(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
1 March 2001 (01.03.2001)

PCT

(10) International Publication Number
WO 01/14782 A1

(51) International Patent Classification[7]: F16L 55/00

(21) International Application Number: PCT/IL00/00499

(22) International Filing Date: 20 August 2000 (20.08.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
131590 25 August 1999 (25.08.1999) IL

(71) Applicant *(for all designated States except US)*: **CORE FLOW LTD.** [IL/IL]; P.O. Box 6937, 31068 Haifa (IL).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **LEVIN, Daniel** [IL/IL]; Heinrich Heinne Str. 16, 34485 Haifa (IL). **YASSOUR, Yuval** [IL/IL]; Bikurim Str. 8, 31061 Haifa (IL).

(74) Agent: **MILLER - SIERADZKI, ADVOCATES & PATENT ATTORNEYS**; P.O. Box 6145, 31061 Haifa (IL).

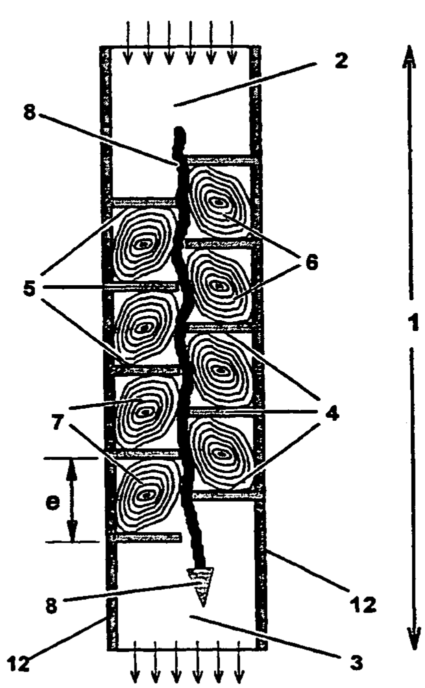
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: SELF ADAPTIVE SEGMENTED ORIFICE DEVICE AND METHOD



(57) Abstract: A flow control device comprising a fluid conduit (12), having an inlet (2) and outlet (3), said conduit provided with at least three fins (4 and 5) mounted on the internal wall of said conduit wherein two of said three fins and a portion of said conduit internal wall define a cavity and the third of said three fins positioned opposite said cavity, whereby when fluid flows through said conduit at least one substantially stationary vortex (6 and 7) is formed in said cavity said vortex existing at least temporarily during said flow thus forming an aerodynamic blockage allowing a central core-flow (8) between the vortex and the tip of said third fin and suppressing the flow in a one-dimensional manner, thus limiting the mass flow rate and maintaining a substantial pressure drop within the conduit.

WO 01/14782 A1

SELF ADAPTIVE SEGMENTED ORIFICE DEVICE AND METHOD

FIELD OF THE INVENTION

The present invention relates to Fluid Mechanics. More particularly it relates to a self adaptive aerodynamic (or hydrodynamic) blockage apparatus and a method for producing a self adaptive segmented orifice device and method, designed to provide aerodynamic (or hydrodynamic) blockage, and create in effect a dynamic orifice.

BACKGROUND OF THE INVENTION

A through flow duct of any reasonable configuration, an orifice, as well as open channels (hereafter generally referred to as "conduit") are all accessories through which fluid flows. The internal geometry of the conduit may be designed to limit or control the through flow.

The term "Fluid", In reference to the present invention, is used in its broader sense, to include gases or liquids, Newtonian or non-Newtonian fluids, one or two phase fluids, multi-component fluids, fluids containing solid particles, fluids that include organic and chemical substances in a solid or non-solid state, as well as "granular flow", like sand, powders, or any solid particles that dynamically obey the continuity assumption. The term "Flow" that represents the motion of the fluid, may involve, in respect to the present invention, several fundamental characteristics of a fluid-flow, such as steady or unsteady flow, of laminar, transitional or turbulent characteristics. The flow field may be compressible or incompressible (including acoustic phenomena). The flow Reynolds number (Re) can vary greatly, as long as viscous effects are not dominant . In particular, the Re number may be as low as an order less than 10, where the conduit through which the flow passes is of very small lateral scale and viscosity effects are significant but not dominant, and up to high Re numbers, where the conduit is of large lateral scale, which means that the flow is "almost" non-viscous, excluding thin boundary layers attached to the conduit internal walls. The "driving force", with respect to the present invention, is an external pressure difference imposed between the inlet and the outlet of the conduit. It may alternatively be the water level differences in open channel type of conduits.

The internal geometry of the conduit determines the characteristics of the flow through it. In particular, it determines the Mass Flow Rate, hereafter referred to as MFR,

as well as the downstream velocity and pressure distribution and, for compressible fluids, the density and the temperature distribution of the fluid.

Controlling MFR through the conduit is considered a common engineering task. Under given external conditions, it may be customary to reduce the conduit lateral size (or its "hydraulic diameter"), in order to limit or control MFR. However, reducing the physical size of the conduit does not always prove to be a good solution for achieving practical engineering requirements. This is the case when, for instance, the conduit lateral scale is extremely reduced, and the nature of the flow may significantly be dominated by viscous effects.

Moreover, in many cases, reducing the conduit lateral size in order to limit MFR, can be impractical or be an unsatisfactory solution. This is true when the external conditions are varying with respect to time, where the performance of a conventional fixed-geometry conduit is not adequate to provide the anticipated engineering requirements at such alternating conditions. This is also true when the fluid contains contaminants, which may bring about mechanical blockage of the conduit. Furthermore, such solutions are totally impractical to use when two or more conflicting requirements are set - when reducing the lateral size serves one objective, but fails to serve the other one. Conventional solid "devices" can provide a partial or limited solutions in respect to MFR, but they are usually insufficient in respect to controlling the internal pressure drop, or eliminating the risk of mechanical blockage.

One conventional solution for controlling MFR is a "valve-type" device, an apparatus with moving elements. MFR control is obtained by changing the valve internal geometry. Such devices usually involve mechanical parts such as springs, screws and membranes, and Electro-mechanical means of control may also be used. Such devices may be manually or automatically actuated.

At the high end, expensive, actively controlled devices, of automatically adaptive character, such as Flow Control Valve, or Pressure Control Valve, have been known and are widely in use. These valves provide precise control of the out coming MFR, or of the exit pressure respectively, regardless of the external conditions. Such control valves may be based on pure mechanical features or by employing electronic controllers.

One common passive way to reduce MFR, without employing any moving parts, is by using a labyrinth-like through-flow conduit, common in the field of irrigation. In such solid configuration devices, the flow impinges on the facing walls while changing its direction, and a sinusoidal type of flow is established. As the contact surface between the fluid and the conduit walls considerably increases and/or the near wall fluid velocity gradients increase, much larger viscous friction forces are generated. Alternatively, it can be said that by applying viscous effects, the fluid-dynamic resistance of the conduit is

increased. With the increase of the fluid-dynamic resistance, the MFR through the conduit is reduced, and the internal downstream pressure gradients are increased.

The only related prior art references having some relevance to the present invention deal with irrigation emitters only where the fluid passing through it is water which is practically incompressible (as opposed to air or other gases).

US Patent No. 3,896,999 (Barragan) disclosed an anti-clogging drip irrigation valve, comprising a wide conduit equipped with a plurality of partition means, integrally formed with the conduit wall, forming labyrinth conduits, in order to reduce the water pressure prior to its exit through the labyrinth conduits outlet.

US Patent No. 4,573,640 (Mehoudar) disclosed an irrigation emitter unit providing a labyrinth conduit similarly to the valve in US Patent No. 3,896,999. Examples of other devices providing labyrinth conduits for the purpose of providing a pressure drop along the conduit can be found in US Pat. No. 4,060,200 (Mehoudar), US Pat. No. 4,413,787 (Gilead et al.), US Pat. No. 3,870,236 (Sahagun-Barragan), US Pat. No.4,880,167 (Langa), US Pat. No.5,620,143 (Delmer et al.), US Pat. No. 4,430,020 (Robbins), US Pat. No. 4,209,133 (Mehoudar), US Pat. No. 4,718,608 (Mehoudar), US Pat. No. 5,207,386 (Mehoudar).

In a labyrinth conduit the aerodynamic resistance is substantially large due to the viscous friction exerted by the walls of the conduit (acting opposite to the direction of the flow), and as the passage becomes tortuous and lengthier (that's the essential feature of a labyrinth) more wall contact surface is acting on the flow, increasing the viscous friction. In some cases cavities are provided for intercepting contaminants and for freeing the flow passage. None of these patents, which basically deal with two dimensional geometry (the third being either very small or degenerated), mention or make use of a vortical aerodynamic blockage mechanism, that is an essential feature of the present invention.

In an article titled "A FLOW VISUALIZATION STUDY OF THE FLOW IN A 2D ARRAY OF FINS" (S. Brokman, D Levin, Experiments in Fluids 14, 241-245 (1993)) a study of the flow field in a 2D arrangement of fins was carried out by means of flow visualization in a vertical flow tunnel. The study was related to an earlier studies that examined the fin arrangement as a conceptual heat sink. The above mentioned study went further to examine the complex flow field structure in order to obtain a better understanding of the heat convection process. A model was built of several series of fins, simulating a spatially unlimited multi-cell structure. Two main flow structures were observed – a flow separation from the leading edge of each fin, which due to the influence of neighboring fins, was reattached to the fin, creating a closed separation zone, and a vortex, that filled that closed separation zone.

It is the purpose of the present invention to provide a self-adaptive through-flow

conduit that would adapt itself, in a favorable way, to changing flow conditions.

It is another purpose of the present invention to harness vortical aerodynamic blockage mechanism and incorporate it in a conduit in order to provide a conduit which on one hand can reduce the mass flow rate through it, and on the other hand can increase the pressure drop within, thus obtaining a flow control tool for various purposes (some of which would be explained hereafter).

It is yet another object of the present invention to provide a solid device with no moving parts that would facilitate the control of MFR and the internal downstream pressure drop.

An aspect of the present invention is the employment of vortical aerodynamic blockage to establish such control.

BRIEF DESCRIPTION OF THE INVENTION

The main aspect of the present invention is a definition of internal configurations for a new type of a conduit. These internal configurations are aimed at generating an aerodynamic blockage when a fluid flows through the conduit, thus allowing manipulation and control of the through flow passing through the conduit, as well as improving its practical features and gaining new engineering options.

It is therefore provided, in accordance with a preferred embodiment of the presnt invention,

a flow control device comprising a fluid conduit, having an inlet and outlet, said conduit provided with at least three fins mounted on the internal wall of said conduit wherein two of said three fins and a portion of said conduit internal wall define a cavity and the third of said three fins positioned opposite said cavity; whereby when fluid flows through said conduit at least one substantially stationary vortex is formed in said cavity said vortex existing at least temporarily during said flow thus forming an aerodynamic blockage allowing a central core-flow between the vortex and the tip of said third fin and suppressing the flow in a one-dimensional manner, thus limiting the mass flow rate and maintaining a substantial pressure drop within the conduit.

Furthermore it is provided, in accordance with a preferred embodiment of the presnt invention, a flow control device comprising a fluid conduit, having an inlet and outlet, said conduit is provided with a plurality of fins mounted on the internal wall of said conduit said fins arranged in two arrays substantially opposite each other; wherein each of the fins of either one of said fin arrays excluding the fin nearest to the inlet and the fin nearest to the outlet of said conduit is positioned substantially opposite one of a plurality of cavities each

cavity defined between two consecutive fins of one of said arrays of fins and a portion of said conduit internal walls wherein said two opposing fin arrays are arranged asymmetrically; whereby when fluid flows through said conduit a plurality of vortices are formed within said cavities one vortex in a cavity said vortices existing at least temporarily during said flow thus forming an aerodynamic blockage allowing a central core-flow between said vortices and the tips of said fins suppressing the flow in a one-dimensional manner, thus limiting the mass flow rate and maintaining a substantial pressure drop within the conduit.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said fins are L-shaped where a thin core-flow is suppressed in a two-dimensional manner by said vortices.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said fins are U-shaped where a thin core-flow is suppressed in a two-dimensional manner by said vortices.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit follows a straight path.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit follows a tortuous path.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit cross-section is substantially rectangular.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit cross-section is substantially polygonal.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit cross-section is substantially circular.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the downstream distribution of said conduit cross-section area is uniform.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the downstream distribution of said conduit cross-section area is divergent.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the downstream distribution of said conduit cross-section area is convergent.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said fins are substantially perpendicular to said internal wall of the conduit.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said fins are inclined with respect both to the general core-flow direction of motion and to the conduit internal walls.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the average thickness of each of said fins is smaller in order compared to the distance

between said fin and the next consecutive fin of the same fin array.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the fin cross-section is substantially rectangular.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the fin cross-section is substantially trapezoidal.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the fin cross-section is substantially concave at least on one side.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the distance between two consecutive fins is constant along the conduit.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the distance between two consecutive fins varies along the conduit.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the span of each of said fins is uniform along the conduit.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the span of said fins varies along the conduit.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the span of said fin is laterally uniform.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the span of said fin laterally varies.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the tips of said fins are sharp.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the tips of said fins are blunt.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the tips of said fins are curved.

Furthermore, in accordance with a preferred embodiment of the presnt invention, each of said fins substantially blocks half of the conduit lateral width.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the two opposite fin arrays do not overlap.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the two opposite fin arrays overlap.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the ratio between the fin span and the gap between that fin and a consecutive fin of the same array of fins is in the range of 1:1 to 1:2.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the said ratio is about 1:1.5.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the

absolute value of the gap between the virtual plane connecting the fin tips of one of said two opposite fin arrays and the virtual plane connecting the fin tips of the second of said two opposite fin arrays is of smaller order than the lateral width of said conduit.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said absolute value of said gap is not more than 20% of the adjacent lateral width of said conduit.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the size of each of said cavities is slightly smaller than the integrally defined natural scales associated with the vorticity of the vortex formed inside said cavity.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the said conduit passive dimension defined as the dimension substantially parallel to said vortices virtual axes and substantially perpendicular to said core-flow motion is in the order of the fins span.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said passive dimension is substantially larger than the other lateral dimension of the conduit that is substantially perpendicular to both the vortex axis and to the core-flow motion.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said passive dimension follows a close substantially annular route.

Furthermore, in accordance with a preferred embodiment of the presnt invention, when Reynolds Number is increased inside said conduit further secondary vortices are formed.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said core-flow downstream motion is substantially sinusoidal.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the sinusoidal core-flow strongly interacts with the fins by local impingement of the core flow with the surfaces of the fins facing its motion.

Furthermore, in accordance with a preferred embodiment of the presnt invention, when Reynolds Number is increased inside said conduit said core-flow breaks down locally and frequently generates unsteady secondary vortices intensively interacting with the core-flow or impinging on the surface of the facing fin.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the device is used for controlling the transfer of fluids flowing through the device.

Furthermore, in accordance with a preferred embodiment of the presnt invention, it used for generating fluidically induced forces.

Furthermore, in accordance with a preferred embodiment of the presnt invention, it is incorporated in a heat exchanger.

Furthermore, in accordance with a preferred embodiment of the presnt invention, it used as a silencer.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit when closed at its inlet generates suction forces or transfers vacuum conditions from the outlet to the inlet.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit when closed at its outlet generates pressure forces or transfers pressure conditions from the inlet to the outlet.

Furthermore, in accordance with a preferred embodiment of the presnt invention, when said conduit outlet is almost closed it employs dramatic changes imposed on the aerodynamic blockage as it is about to collapse.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit is an open channel of water said channel has an inlet at a higher level water reservoir and an outlet at a lower level water reservoir where said plurality of fins are positioned substantially vertical with respect to gravity and also substantially perpendicular to the water direction of motion thus vertical vortices are formed between the floor of said channel and the contact-layer between the water and the air, whereby the flow of water is controlled by said aerodynamic blockage.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the fins span varies parallel to said vortices, thus obtaining changing hydrodynamic blockage effects with respect to the water level.

Furthermore, in accordance with a preferred embodiment of the presnt invention, a plurality of said channels are combined together in parallel to act as a breakwater with the inlets directed to the open sea and the outlets directed to the land side whereby allowing the migration of sand through said breakwater.

Furthermore, in accordance with a preferred embodiment of the presnt invention, it is provided a flow control device comprising a conduit having an inlet and an outlet said conduit is provided with a helical fin mounted on the internal wall of said conduit thus a helical cavity is formed defined by said helical fin and said internal wall; wherein when a fluid flows through said conduit a helical vortex is formed within said helical cavity said helical vortex exists at least temporarily during said flow thus forming an aerodynamic blockage allowing a central core-flow between said vortex and the tip of said helical fin and suppressing the flow in a two-dimensional manner, thus limiting the mass flow rate and maintaining a substantial pressure drop within the conduit; whereby said core flow flows through a central passage defined by the helical fin internal edge and may locally bypass an obstruction in said central passage by following the helical passage adjacent the helical fin.

Furthermore, in accordance with a preferred embodiment of the presnt invention, at least one barrier of a plurality of barriers is mounted substantially normally to said helical fin

surface thus locally blocking the helical path to prevent the flow from following the helical path and thus said helical vortex locally splits by said barriers to at least two fragments.

Furthermore, in accordance with a preferred embodiment of the presnt invention, at least one barrier out of two barriers is mounted substantially normally to the fin surface on one of the two ends of said helical fin to act as anchorage for said helical vortex.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit follows a straight path.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit follows a tortuous path.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit cross-section is substantially circular.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit cross-section is substantially rectangular.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit cross-section is substantially polygonal.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the downstream distribution of said conduit cross-section area is uniform.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the downstream distribution of said conduit cross-section area is divergent.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the downstream distribution of said conduit cross-section area is convergent.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said helical fin is substantially perpendicular to said internal wall of the conduit.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said helical fin is inclined with respect both to the general core-flow direction of motion and the to conduit wall.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said helical fin thickness is smaller in order with comparison to said helical fin pitch.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the helical fin cross-section is substantially rectangular.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the helical fin cross-section is substantially trapezoidal.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the helical fin cross-section is substantially concave at least on one side.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said helical fin pitch is constant along the conduit.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said

helical fin pitch varies along the conduit.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the span of said helical fin is uniform.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the span of said helical fin varies along the conduit.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the tip of said helical fin is sharp.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the tip of said helical fin is blunt.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the tip of said helical fin is curved.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said helical fin span is substantially half of the said conduit lateral width.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the ratio between the helical fin span and the helical fin pitch is in the range of 1:1 to 1:2.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said ratio is about 1:1.5.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the central passage defined by the helical fin tip is of smaller order in comparison with the hydraulic diameter of said conduit.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said gap is not more than 30% of the adjacent lateral width of said conduit.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the size of said helical cavity is slightly smaller than the integrally defined natural lateral scales associated with the vorticity of the said helical vortex.

Furthermore, in accordance with a preferred embodiment of the presnt invention, when Reynolds Number is increased inside said conduit further secondary vortices are formed.

Furthermore, in accordance with a preferred embodiment of the presnt invention, the core-flow strongly interacts with said helical fin by local impingement with the surface of the helical fin facing its motion.

Furthermore, in accordance with a preferred embodiment of the presnt invention, when Reynolds Number is increased inside said conduit said core-flow breaks down locally and frequently generates unsteady secondary vortices, intensively interacting with the core-flow or impinging on the facing fin.

Furthermore, in accordance with a preferred embodiment of the presnt invention, it used to transfer fluids.

Furthermore, in accordance with a preferred embodiment of the presnt invention, it used

to generate fluidically induced forces.

Furthermore, in accordance with a preferred embodiment of the presnt invention, it used as a silencer.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit when closed at its inlet generates suction forces or transfers vacuum conditions from the outlet to the inlet.

Furthermore, in accordance with a preferred embodiment of the presnt invention, said conduit when closed at its outlet generates pressure forces or transfers pressure conditions from the inlet to the outlet.

Furthermore, in accordance with a preferred embodiment of the presnt invention, when said conduit outlet is almost closed it employs dramatic changes imposed on the aerodynamic blockage as it is about to collapse.

Finally, in accordance with a preferred embodiment of the presnt invention, it is provided a flow control method for the control of flow of fluids from higher energy reservoir to lower energy reservoir, said method comprising providing at least one solid partial blockage and at least one complementary vortical flow structure in a conduit through which a fluid flows whereby said solid partial blockage and said complementary vortical flow structure act as an aerodynamic blockage.

BRIEF DESCRIPTION OF THE FIGURES

In order to better understand the present invention, and appreciate its practical applications, the following Figures are provided and referenced hereafter. It should be noted that the Figures are given as examples only and in no way limit the scope of the invention as defined in the appending Claims. Like components are denoted by like reference numerals.

Fig. 1a illustrates a longitudinal cross section view of a Self Adaptive Segmented Orifice Device, in accordance with a preferred embodiment of the present invention, with existing through-flow and formed vortices.

Fig. 1b illustrates a longitudinal cross section view of a Self Adaptive Segmented Orifice Device, in accordance with a preferred embodiment of the present invention, highlighting some of its features for explanatory purposes.

Figs. 2a and 2b illustrate some optional configurations of SASO-device conduits in accordance with a preferred embodiment of the present invention.

Fig. 3a-h illustrate some possible interactions between various vortical flow patterns with the SASO-cell walls and with the core-flow.

Fig. 4a illustrates a sectional partial view of a SASO-device in accordance with a preferred embodiment of the present invention, depicting Radial Self-Adaptive Gate Unit (SAGU).

Fig. 4b illustrates a sectional partial view of a SASO-device in accordance with a preferred embodiment of the present invention, depicting Tangential Self-Adaptive Gate Unit (SAGU).

Figs. 5a-5c illustrate lateral aspects of the core-flow motion, including impingement with the fins of a SASO-device in accordance with a preferred embodiment of the present invention.

Figs. 6a-6c illustrate geometrical aspects of the fins structure and of fins arrangement of a SASO-device in accordance with a preferred embodiment of the present invention.

Fig. 7a-c display a three-dimensional view, and three cross-sectional side views of a SASO-device in accordance with a preferred embodiment of the present invention, and presents optional fin-surface formation, of a SASO-device in accordance with a preferred embodiment of the present invention.

Fig. 7d-f depicts three optional fin alignment and fin construction incorporated in a SASO-device, in accordance with a preferred embodiment of the present invention, rendering a "Directional" SASO-device.

Figs. 8a-b illustrate an annular SASO-slot, in accordance to a preferred embodiment of the present invention.

Figs. 9a-d illustrates a SASO-device, in accordance with another preferred embodiment of the present invention, with L-shaped fins (or U-shaped fins), exhibiting 3-dimensional core-flow suppression.

Fig. 10 illustrates a SASO-device, in accordance with another preferred embodiment of the present invention, with single helical fin, exhibits 3-dimensional core-flow suppression and dual passage character.

Figs. 11a-c illustrate a SASO-device, in accordance with another preferred embodiment of the present invention, in an open-channel configuration.

Fig. 12 illustrates a low-weight porous breakwater constructed of a plurality of parallel SASO-open-channels, in accordance with another preferred embodiment of the present invention, facilitating sand migration through the breakwater construction.

Fig. 13 illustrates a heat exchanger comprising a plurality of parallel SASO-conduits, in accordance with another preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION AND FIGURES

The present invention, discloses a Self Adaptive Segmented Orifice device (hereafter referred to as SASO). SASO is a novel self adaptive flow control technology (hereafter referred to as SASO-technology), based on aerodynamic blockage mechanism. SASO-technology is implemented in a wide variety of components, elements or devices (hereafter referred to as SASO-device), to be used for the any possible SASO-applications.

SASO-technology utilizes aerodynamic blockage to manipulate the fluid motion inside a specially designed conduit as explained in detail hereafter. Note that the term "aerodynamic" may be replaced with "hydrodynamic" depending whether gas or liquid are considered as the acting fluid. In practice, SASO-device is essentially a conduit with a predetermined internal configuration that imposes the development of a unique vortical flow field pattern inside the conduit. This flow field imposes an aerodynamic blockage mechanism that radically increases the fluid dynamic resistance. It is effective, only in dynamic conditions, when there is a fluid motion through the conduit.

The aerodynamic blockage mechanism of the SASO is hereby explained with reference to the Figures. The SASO-device basic two dimensional configuration in accordance with a preferred embodiment of the present invention comprises a conduit (1), provided with an inlet (2), and outlet (3), having a plurality of fins arranged in two arrays (4, 5), substantially at opposing sides on the inside of the conduit walls (12), as illustrated in Figure-1a. The two fin arrays are arranged in a relative shifted position, where opposite to the gap formed between two successive fins of the first array of fins (apart from both end fins), there exists one opposite fin of the second array, thus creating the typical asymmetric configuration that characterizes SASO-devices. Consequently, two asymmetrical arrays of cells are formed, each cell bounded by two consecutive fins of the same array, and a portion of the conduit wall in between them. Thus a cavity is defined, where a large vortex may develop inside it when a fluid flows through the conduit (this cavity, hereafter referred to as SASO-cell).

The SASO-device internal configuration dictates the unique vortical flow field pattern established inside the conduit, when a fluid flows through it. Each one of the fins imposes a separation of the flow downstream from the fin's tip. Further downstream, a large fluid structure. a vortex. is generated inside each of the SASO-cells. A vortex is a circular motion of fluid around a virtual axis, where the term "circulation" defines the vortex intensity. A vortex is generated by a well-known roll-up mechanism of the separated shear flows. following the flow separation from the upstream fin of each SASO-

cell. Beside the main dominant vortices, secondary vortices may develop, playing an important role in the enhancement of SASO-device performance. An optional prominent feature is the unsteady nature of the main vortices, as well as unsteady modes of the secondary vortical flow patterns, that may significantly augment the aerodynamic blockage effect.

In practice, a flow pattern of two opposite rows of vortices (6,7), is developed, and is asymmetrically arranged, as shown in Figure-1a. Each vortex is located inside a SASO-cell, facing an opposite fin. These vortices, and in particular when formed with almost closed stream lines, practically block the flow through the conduit, thus preventing the development of a wide sinusoidal fluid motion, a type of fluid motion that characterizes labyrinth-like conduits. Consequently, a significantly thin core-flow (8), is developed between the blocking fins and the vortices. The core-flow may be of a relatively high downstream velocity, and it is bounded on two sides by the vortices and do not touch the conduit walls . Hence, as the core-flow instability increases, it breaks down and may frequently generate unsteady secondary vortices, shed downstream and intensively interacting with the core-flow. An impingement of the core-flow with the facing fins may also occur, following the core-flow breakdown. In addition, wavy flow patterns of periodic or chaotic nature may develop. Such interactions may significantly enhance the aerodynamic blockage effects. Figure-1a, which shows schematically a two dimensional longitudinal cross-section through a typical SASO-device conduit, presents a basic SASO-device, with a fully developed vortical flow pattern and vortices present. A SASO-device is a three-dimensional conduit, but can in practice be of essentially two-dimensional nature where the third direction perpendicular to both the core-flow motion and the main vortices virtual axes (hereafter referred to as the "passive direction"). Hence, the illustration of the SASO-device given in Figure-1a should be considered as the cross-section of a practical device.

When flow exists through the conduit, the two set of vortices block the flow, allowing thus only a very narrow core-flow 8 to develop between the arrays of the vortices and the fins tips. Since the MFR through a SASO-device is mainly conveyed by the core-flow, such a blockage dramatically reduces the MFR. Moreover, additional MFR reduction may be obtained when non-steady interactions between the core-flow and secondary shed vortices occurs inside the SASO-device conduit. The vortical aerodynamic blockage substantially increases the internal pressure drop (hereafter referred to as ΔP), along the conduit. It results from the interaction between the vortices and the SASO-cell walls.

The substantially reduced MFR and the drastic increase in ΔP, are fundamental features of great practical importance in SASO-technology. It should be noted, however,

that these important features are obtained only when flow through the conduit exists, where if there is no flow, no vortices are developed. This "dynamic" nature is the essence of the SASO-idea that may be defined as follows:

- The special configuration of a SASO-device conduit intentionally dictates the development of the vortical flow patterns.
- The vortical flow pattern, by implementing aerodynamic blockage mechanism, is responsible for blocking the flow in a self-adaptive manner, thus reducing the MFR and increasing the ΔP.
- It is effective only during the dynamic state, when there is flow through the conduit.
- Unsteady cases where the vortical flow patterns are effective only for an essential portion of time, out of the entire operational duration, are also included within the scope of the present invention.

It has to be emphasized that there is a wide variety of possible SASO-device configurations (some of them will be discussed later). Therefore, as long as any device or product essentially implements the vortical aerodynamic blockage mechanism, as dictated by the special internal geometry of the SASO-conduit, it is inherently a SASO-device, and covered by the scope of the present invention. It is true regardless of the specific geometry of the SASO-device.

SASO-device is generally a solid body without any moving parts. It does not involve a need for any mechanical parts (such as springs, membranes etc.), or employ Electro-mechanical control means. It can be made of metallic material as well as non-metallic material, such as plastics. Nevertheless, its self-adaptive behavior with respect to external conditions yields a new type of device, where the regulation of the MFR and ΔP is achieved by applying the aerodynamic blockage mechanism of the present invention.

The aerodynamic blockage mechanism is the basic self-adaptive nature of the SASO-device. However, additional aspects of self-adaptive nature are associated with it. Apart from the primary vortices that develop within the SASO-cells, additional vortical flow mechanisms of self-adaptive nature might alternatively or simultaneously be developed at different imposed external conditions, or in response to varying external conditions. When increasing the external pressure drop or when the Reynolds number is intentionally increased, the following vortical flow patterns that modify the aerodynamic blockage mechanism may be involved:

- The intensity (circulation) of the primary vortices may intensify.
- The downstream distribution of the vortices intensity may vary.
- The number of effective vortices inside a conduit may change.
- Vortex fluttering modes, mostly of periodic nature may be excited.

- Secondary shed vortices strongly interacting with the core-flow or with the facing fins may develop.

Such patterns significantly increase the overall aerodynamic blockage efficiency.

As a consequence of the vortical aerodynamic blockage effects, the SASO-device has a unique response during transient operational periods like starting or stopping sequences, or when external conditions such as the pressure drop between the inlet and the outlet are altered. SASO-device response to such transient conditions can be designed to achieve favorable transient behavior such as fast or slow response, smooth response, etc

Figure-1b demonstrates the geometrical aspects of the present invention. The following detailed description of the various SASO-device structural elements, is given with the essential functioning of each of the elements as well as its influence on SASO-device characteristics and the way it affects the vortical flow patterns that block the flow. The first element is the SASO-device conduit (9), which connects between two "reservoirs" of different pressure, one located adjacent to the ,inlet (2), and the other located adjacent to the outlet (3) of the conduit. The SASO-device conduit may be stretched in a straight line (Figure-2a, 200), or aligned along a tortuous course (Figure-2a, 201,202). Figure-2a shows only 2-dimensional courses, however the SASO-device conduit course can also be tortuous in a three-dimensional manner, thus the fluid may be conveyed to any desirable direction, distance and location. The downstream distribution of the conduit's cross-section area may be uniform (Figure-2a, 200), divergent (Figure-2b, 203), convergent (Figure-2b, 204), or of any other practical distribution. The conduit cross-section might be of rectangular (Figure-6a, 220,222), substantially circular (Figure-6a, 221,224), Polygon (Figure-6a, 223), or of any other shape dictated by the specific engineering needs.

The lateral dimension of the SASO-device conduit is denoted by "*a*" (see Figure-1b). The internal wall surface of the SASO-device conduit may be smooth or rough to enhance small scale turbulence within the thin boundary layers, attached to the conduit walls. In the case of rough walls, the skin friction is augmented. For the same matter, the conduit internal wall may also be provided with small extruding obstacles, preferably not greater than the boundary layer width, to enhance local flow separation that triggers wall turbulence.

Fin (13) is a member of one of the two opposite fin arrays (14,15), forming the special internal geometry of the SASO-device. The objective of the fins is to force flow separation, and consequently to generate the vortical flow patterns. The fins may be positioned perpendicularly to the conduit walls, thus facing the flow, as illustrated in

Figure-1b, Alternatively, the fins may be inclined with respect to both the general core-flow direction and the conduit walls. The surfaces of the fin may be flat or of any other predetermined surface geometry, to manipulate the separation characteristics.

A typical fin span of a fin from one fin array is denoted by the dimension "*b*", as shown in Figure-1b. The fin span of a fin of the opposite fin array, closest to the first fin of the first fin array, is denoted by "c". The fin span of both fin arrays can be uniform as illustrated in Figure-1b, or varying. The fin tip (16) may be sharp or blunt, or of any reasonable shape. Preferably each of the fins substantially blocks half of the conduit, thus "*b*" and "c" are each substantially half of the hydraulic diameter "*a*". The gap between the two opposite arrays of fins is "*d*"=*a-(b+c), as* shown in Figure-1b. There are three practical possibilities for the value to "*d*":

d is greater than zero (see Figure-6b, 212) : An almost straight core-flow is developed as shown in Figure-5a.

d approaching zero (see Figure-6b, 211) : The gap is substantially diminished and the core-flow becomes sinusoidal as illustrates in Figure-5b.

d is smaller than zero (see Figure-6b, 213) : The fins partially overlap and the sinusoidal motion is amplified.

In fact, for the purposes of implementation of the principles of the present invention, the absolute value of "*d*" should be of a smaller order than the lateral dimension of the conduit "*a*". Preferably said absolute value of said gap is not more than 20% of the adjacent lateral width of said conduit.

The development of the core-flow's laterally sinusoidal motion does not exclusively depend on the gap "*d*" but also on the geometrical details of the fins. In addition, the laterally sinusoidal motion may be amplified when the Reynolds Number of the through flow is increased. When intensive core-flow motion exists, local impingement of the core-flow at the edge area of the fins facing surface may be developed as shown in Figure-5c.

The fin shape, and in particular the shape of the fin tip, may significantly affect the SASO-device performance, since the flow separates from the fin tip. The fin tip can be sharp (Figure-6c.230), round (Figure-6c,231) or of blunt cut (Figure-6a, 232,233). The fin tip is usually a curve in real three dimensional cases, and the "separation point" is in fact a "separation curve", which is substantially normal to the core-flow motion direction. The "separation curve" may be a straight line, or of any predetermined curvature, in correspondence to the fin tip curvature or the lateral distribution of the fin span. The fin span can be laterally uniform (Figure-7c, 241), roundly curved (Figure-7c, 242), symmetrically "V" shaped (Figure-7c, 243), or laterally inclined (Figure-7c, 244), The "separation curve" may be fixed (stationary) to a substantially sharp or blunt fin tip, or of a non-stationary behavior. The non-stationary behavior can be dictated by the use of a

round fin-tip. The fin surface may be smooth or rough, to generate small scale boundary layer turbulence. In particular, by using roughness in the fin-tip region, especially in round fin-tip cases, the characteristics of the flow separation might be manipulated. Unsteady character of the flow separation may significantly improve the SASO-device performance, as it may trigger complex unsteady vortical flow patterns that may block the through flow more efficiently.

In practice, a SASO-device includes a plurality of fins. Thus various fin combinations may be configured inside the conduit, to provide a SASO-device with improved characteristics. Without derogating generality the following combinations are available :

- One fin type with constant geometrical profile throughout the entire SASO-device.
- One fin type, but the fins geometrical profile change in the downstream direction. For example, a divergent distribution of the free gap "*d*" (see Figure-7d), or alternatively, a convergent distribution.
- A combination of fin types. Although the use of one fin type is preferable.
- The fins may be inclined relative to the main flow motion.

Any shape of fin, of any geometric details mentioned above, is allowed in the SASO-device, as long as the fundamental SASO-idea of vortical aerodynamic blockage mechanism is established, as a result from the flow separation off the fins.

The last geometrical element to be defined is the SASO-cell (17), shaded by diagonal lines in Figure-1b. SASO-cell is a cavity that is bounded by two consecutive fins (18,19), the conduit wall (20), and the conduit's center-line (21). The SASO-device comprises two substantially opposite arrays of consecutive SASO-cells, where in opposite each SASO-cell of the first set there exists one fin of the opposite set, as shown in Figure-1b. The basic lateral scale of SASO-cell is substantially the fin height, "*b*" (or "*c*"), or approximately half of the conduit lateral dimension, "*a/2*". The longitudinal gap between the fins, denoted by "*e*" in Figure-1b, is the SASO-cell pitch. Although it usually is the case, it is not always necessary to place the opposite fin facing the exact center of SASO-cells of the opposite set, and it may be off the center. The SASO-cell pitch "*e*" can be constant. or of any practical downstream distribution.

In the cavity of the SASO-cell, the primary vortices are developed. The developed vortices are dynamic fluid structures that develop and survive within the SASO-cell, only when through flow is maintained inside the conduit. A vortex is a rotational motion of fluid around a fixed or an unsteady virtual axis. A steady vortex is a fully developed vortex, that induces a steady velocity field. In cases of a steady state situation, the primary vortex is characterized by closed stream-lines as illustrated in Figures 1a and 1b. It means that

there is no mass flow normal to the vortex, thus it may serve as an efficient fluid barrier, just like the solid fins that face the incoming flow. When the primary vortex is of unsteady nature, but still maintained substantially within the SASO-cell, it may be distorted while moving periodically, or even chaotically. In such unsteady cases, the vortex streamlines are not necessarily closed and there is some mass exchange with the core-flow. Nevertheless, practically speaking, the vortex still serves as an effective "fluid" barrier. The unsteady nature of the primary vortices is of great importance in accordance to the present invention, because it can trigger complex interactions between the vortices and the core-flow. It can also trigger longitudinal interactions between the vortices. These interactions can be intentionally invoked and may significantly improve the aerodynamic blockage efficiency.

The vortical flow patterns strongly interact with the walls of the SASO-cell, involving viscous wall friction. The cases of steady and unsteady viscous interactions should be treated separately. Without derogating generality, Figures 3a-3h illustrate some possible interactions between various vortical flow patterns with the SASO-cell walls, where interactions with the core-flow may be involved. An interaction of a steady character is shown in Figure-3a, where the principle substantially stationary vortex (6) is developed inside the SASO-cell. Figure-3b illustrates the case where weak non-steady interaction, mostly of a time-periodic nature, takes place where the vortex deforms and shifts inside the SASO-cell, and interacts with the core-flow. As the vortex swings about (in the directions represented by arrows (30)), it causes the core-flow to adjust, by locally altering its course to follow the free passage, which shifts accordingly in the direction of arrows (31). The aerodynamic blockage effect may be significantly augmented when unsteadiness is introduced to the flow, for example by selecting the desired scales of the SASO-device. Alternatively speaking, the two fundamental features of the present invention, the drastic reduction of MFR and a significant increase of ΔP, are both modified. Generally, in cases of unsteady vortical patterns, the various aspects of the aerodynamic blockage effects must be treated in terms of time-averaged quantities.

The interactions of the SASO-cell walls with the flow that are shown in Figures 3a and 3b, shed a light on a distinctive aspect of the present invention, resulting from its unique vortical flow mechanism. In such cases, the viscous friction force that acts on the conduit walls is in opposite direction to the viscous force found in conventional or labyrinth-like conduits. It is the vortices inside of a SASO-cell that alter the direction of the viscous friction force. By employing SASO-technology, the direction of the wall viscous friction force can be manipulated, by using secondary vortical flow patterns. Secondary vortices (33) of essentially stationary nature may develop between the principle vortex

and the SASO-cell corners (see Figure-3c). Such small scale vortices can be intentionally initiated with the aid of a special cell geometry, see Figure-3d, where the conduit wall (12) is provided with a extruding construction element (34). Alternatively, when the fin span "*b*" is enlarged a secondary vortex (35), of scales similar to these of the principal vortex, may develop (see Figure-3e). This secondary vortex (35) is usually of a reduced circulation. In other cases, the principle vortex (6) may be forced by the core-flow (8) to a declined orientation inside the SASO-cell cavity. In such a case, a small secondary vortex (35), or several vortices, may develop in the "unoccupied" corner region of the SASO-cell, as shown in Figure-3f. The resulting vortices illustrated in Figures 3c, 3d, 3e and 3f, are in fact a few of many possible SASO-technology tools for manipulating the viscous friction force. Such manipulations may significantly modify the two fundamental features of the SASO of the present invention - reducing MFR and increasing ΔP.

A "free" (geometrically unforced) developed vortex has its own "natural" scales (by this term we mean integrally defined scales associated with its vorticity), that depends on the flow characteristics and its own formation history. The questions of matching between the vortex integrally defined natural scales, and the actual space available inside the SASO-cell, expressed by the term "spacing", is of great importance in the present invention. In the two-dimensional case, the vortex spatial growth is bounded by the SASO-cell walls in a two-dimensional manner. Thus only the vortex cross-sectional aspects of the spacing are relevant to the present discussion, where the geometrical limitation in the passive direction, is further discussed. In certain situations, where the SASO-cell dimensions are effectively larger or smaller than the vortex integrally defined natural scales, the vortex, practically speaking, does not achieve its full potential, thus it is less effective with respect to the aerodynamic blockage mechanism. States of "optimal spacing" might be achieved, practically speaking, when the size of the SASO-cell is slightly smaller than the vortex integrally defined natural scales. In such a case the vortex practically achieves its full potential while it is slightly deformed and intensively interacts both with the SASO-cell walls and with the core-flow. The spacing issue is a most important aspect that affects the SASO-device performance. It is the task of the SASO-technology to define what is the optimal configuration with respect to a specific SASO-application, and to provide the practical design guidelines (to achieve optimal spacing), for a SASO-device design of the best performance. For the case of steady vortices pattern, a recommended approximate ratio of *e/b* is in the range of 1:1 to 1:2, and preferably about 1:1.5. When the SASO-conduit internal configuration is more complex, in particular when three dimensional elements are involved, or in more complex vortical flow patterns. of steady or non-steady nature, or when secondary vortices are developed and

interact with the core-flow and/or the primary vortices, or when the vortical flow pattern is inherently three-dimensional, this ratio may no longer be considered as an initial guideline of the design.

The SASO-device vortical flow pattern becomes more complex and involves unsteady flow mechanisms, as the Reynolds number (Re) increases. When Re number is increased, unsteady secondary vortices may be developed between the core-flow and the principal vortex. The typical scales of these vortices are similar to the core-flow width, and is significantly smaller than the principle vortex. These are shed vortices that may develop and travel downstream in a periodic mode, with complex periodicity or even in a chaotic way. These shed vortices violently interact with the core-flow, and a core-flow of unsteady character is attained. When the shed vortices directly confront the core-flow, unsteady core-flow "break-down", may take place. In addition, local impingement of the core-flow on the facing fins may occur. Shed vortices (36) may exist locally inside the SASO-cell, as illustrated in Figure-3g. They can also travel downstream and interact with the consecutive SASO-cells, see Figure-3h. The unsteady nature of the flow may significantly modify the aerodynamic blockage effect, and affect the fundamental features of the present invention, i.e. reducing the MFR and increasing the ΔP. It is within the scope of SASO-technology to implement and harness the benefits of the unsteady vortical flow patterns.

The appearance of traveling vortices which strongly interact with the core-flow and with the principle vortices may create downstream propagating wavy modes, where a plurality of vortices "communicate" with each other. As a result of direct interactions between the secondary vortices and the core-flow, instantaneous large changes in the lateral and in the longitudinal core-flow velocity may be locally developed. Consequently, the strongly disturbed core-flow may impinge in an unsteady fashion, on the facing fin. As the Reynolds number (Re) is further increased, (for example, by increasing the SASO-conduit lateral scale), more secondary vortices may be generated, and the direct interaction between the vortices and the core-flow becomes more violent. Consequently, the aerodynamic blockage effect can be significantly augmented. Furthermore, SASO-technology provides the necessary know-how required to utilize these unsteady vortices/core-flow interactions for the design of SASO-devices of improved characteristics. The present invention covers all these unsteady secondary vortices patterns. Therefore, the SASO-idea is hereafter extended to include also secondary shed vortices that may instantaneously block the core-flow.

The core-flow lateral scale (or the core-flow width), is significantly narrower than the SASO-conduit hydraulic diameter. The core-flow velocity distribution and its width are

essentially determined by the external pressure drop, the various SASO-device internal configurations, and particularly, by the vortical flow-field patterns that are developed inside the SASO-conduit. When the flow accelerates from rest, the initial core-flow is wider, characterized by a sinusoidal downstream fluid motion of large lateral amplitude, bounded by the fins and the conduit walls. At this first instance, the flow is very similar to the flow in conventional labyrinth type devices. At a later stage, a totally different flow-field develops inside the SASO-device conduit. The flow can not follow the internal passage defined by the walls of the special SASO-device configuration. Consequently, the flow separates at the fin tips, and two opposing rows of intensive principle vortices are developed inside the SASO-cells. These rows of vortices limit the passage of the flow through the conduit, and a detached, severely narrower, core-flow is obtained. In many cases, the core-flow involves unsteady vortical flow patterns, with respect to the predetermined Re number (when Re number is increased).

The core-flow characteristics are affected by the geometry of the SASO-device internal configuration, and to a great extent by the gap, "*d*", between the two opposite arrays of fins. In most cases, as "*d*" is reduced, the core-flow becomes narrower, but as "*d*" is further reduced, a lateral sinusoidal motion may develop. Furthermore, as the gap is closed ("*d*"=0), or when the fins overlap ("*d*"<0), the lateral sinusoidal motion is augmented and the core-flow width may increase. These two contradictory effects bring about the notion that values of "*d*" between $b/10 < d < -b/10$ may be particularly preferable. As one of these contradictory effects intentionally becomes dominant, it may serve practical requirements, when, for example, the reduction of MFR is of interest, but not the maximizing of ΔP, and vise versa.

It has to be noted that as the degree of fin-overlap increases above a certain value, the core-flow might be forced to reattach to the conduit walls. In this case the SASO-idea is no longer sustained, the flow adopts a labyrinth type of motion and the vortical flow pattern disappears. Nevertheless, as long as the core-flow is substantially separated from the fins, and is thus basically different from labyrinth flow types, and as long as the core-flow is dominated by the various types of vortical flow patterns, that block the flow, it maintains the SASO-idea described in the present invention.

The typical width of the core-flow is the effective hydraulic diameter of the SASO-cell conduit. Thus, a SASO-device that has a large lateral physical size ("*a*"), is practically of a much narrower effective width, with respect to the MFR, compared to conventional conduits. In typical cases, the physical size and the effective size, regarding MFR through the SASO-conduit, differ by orders of magnitude. This dual-scale behavior (small effective scale in respect to the MFR and large physical dimensions), is a fundamental feature of

the present invention. In particular, the large physical scale is important with respect to significantly reducing the risk of contamination blockage in the case of fluids containing contaminants. It is further suggested that the physical passage inside the SASO-conduit (i.e. the winding passage within the conduit, between the fins) be greater than the envisaged size of the contaminant particles inside the fluid by at least 10%. The contaminants size can be predicted when the SASO-device is designated for a specific SASO- application, and therefore SASO-conduit scales relevant to that physical passage can be specified.

The discussion until now was limited to a two dimensional case of the SASO-device, in order to simplify the presentation of the flow field and its structure. However, for a true three dimensional SASO-device the "passive dimension" (passive - from topological point of view), physical scale denoted by the width "w" must be large enough so that the viscous edge effects should be negligible. Too small a "w" will render the SASO-device ineffective, as the large velocity gradient between the vortices and the side walls will attenuate the vortices intensity. It is recommended that the minimal width therefore should be at least of the same order of magnitude as "*b*" (see Figure-1b).

The Self-Adaptive Segmented Orifice (SASO), of the present invention brings about two *principal concepts* :

- The Self-Adaptive Gate Unit.
- The Segmentation concept

A discussion of these two concepts follows.

Each vortex and the opposing fin define a "Self-Adaptive Gate Unit" (hereafter referred to as SAGU), which is the fundamental unit of the present invention as illustrated in Figure-1b, depicting a sectional view of a SASO-device in accordance with a preferred embodiment of the present invention. A SAGU is a "virtual" orifice unit consisting of two complementary elements, a solid element - the fin, and a dynamic element - a vortical fluid structure positioned between two fins of the opposite fin array (15). Hence, SAGU is a dynamic entity that exists as long as fluid motion through the conduit is maintained. Two distinct SAGU types are relevant for the present invention:

Radial SAGU - where the fin (13) substantially points toward the vortex (6) core, positioned in the opposite SASO-cell, between two consecutive fins of the opposite fin array (18,19) , as shown in Figure-4a.

Tangential SAGU - where the fin (13) is substantially tangential to the circular motion of the vortex (6), with the fins inclined with respect to the conduit wall (12), defining angle "α" between the fin and wall (12), and introducing a typical distance "*f*" which is the shortest distance between the tip of a fin in one fin array and the closest fin of the second substantially opposite fin array, see Figure-4b. As "*f* " defines in effect the

gap between the opposing fin arrays, the lengthy account given above regarding gap "*d*" applies to "*f*" with the necessary amendments.

A Hybrid SASO-device consisting of both SAGU types is also included in the scope of the present invention.

Due to a significant increase of the fluid-dynamic resistance, a SASO-device incorporating several SAGUs, may be of appealing engineering advantage in two aspects:

- The through-flow is substantially blocked by the vortices, and consequently MFR is dramatically reduced, relative to the MFR through a conventional conduit of the same hydraulic diameter.
- Significantly increased internal pressure drop (ΔP), is developed within the conduit, in comparison to conventional conduits.

It has to be emphasized here that these two aspects are functionally related, and it is SASO-technology that manipulates and exploits this mutual dependence.

The second fundamental substance of the SASO in accordance with the present invention is the segmentation concept. In practice, it is beneficial to employ a combination of SAGUs, to configure a well functioning SASO-device. This is the essence of SASO-technology that provides SASO-devices with new or improved predetermined feature, to fulfill specific engineering requirements for various SASO-applications.

A fundamental aspect of the present invention is the self-adaptive nature of SASO-devices. Such devices respond differently from conventional devices to changing or unsteady external conditions. In particular, SASO-devices are superior when external conditions are not stable or intentionally altered, or when adjustable functionality is required to meet different engineering requirements. Ultimately, the dynamic nature of the vortical flow pattern and the possible interactions of the vortices with the core-flow render the SASO its adaptive behavior.

SASO-technology can be used to manipulate two essentially different engineering aspects:

- A SASO-device can be used to limit or control the motion of any fluid through the conduit, by generating aerodynamic blockage.
- A SASO-device can be used to withhold a substantial internal pressure drop by generating aerodynamic blockage.

The fundamental idea of the present invention is manifested by the following statement: the SASO in accordance with a preferred embodiment of the aerodynamic blockage mechanism imposed by the Self-Adaptive Segmented Orifice of the present invention is effective as long as the SASO-device special configuration imposes the

development of the vortical flow field patterns, thus achieving substantial control over the flow through the conduit.

When the flow through the conduit commences, vortices are not yet developed and therefore initial MFR is relatively large (during a transitional period). A short while later, as the transitional period is over, the vortical flow pattern is fully developed and efficiently blocks the flow through the conduit. As a result, MFR is drastically reduced and the internal pressure drop (ΔP) is significantly increased. This transitional event is responsible for the self-adaptive nature of the present invention. When a fluid starts flowing through the conduit, the SASO-device "reacts" in a self-adaptive manner, as the vortical flow pattern is instantly developed and aerodynamically blocks the flow.

The transitional period also exhibits the multiple-functioning nature of SASO, a most important feature of the present invention, where different performances are exhibited by the SASO-device at different working conditions, or when it operates at varying working conditions. The characteristics of the vortices and consequently MFR and ΔP, strongly depend on various flow-field phenomena and, most importantly, on the internal configuration of the SASO-device conduit that dictates the internal vortical flow patterns.

The *Self-Adaptive Gate Unit*, SAGU, is the basic component of the present invention that features both structural elements and a flow-field element. Therefore a SAGU may be regarded as a "dynamic" type of a gate. A SAGU includes the following elements :

- ◆ One SASO-cell, on one side of the SASO-device conduit walls.
- ◆ One fin of the opposite array of fins (on the opposite conduit wall).
- ◆ One principle vortex, with possible secondary vortices of steady or non-steady nature.

An illustration of one SAGU, shaded with diagonal lines, is given in Figure-1b. A SASO-device may consist of one or more SAGUs, sequentially arranged in an asymmetric configuration as shown in Figure-1b. When a plurality of SAGUs are used, unsteady vortical flow patterns, strong vortices/core-flow interactions and communication between SAGUs may significantly modify the practical characteristics of the SASO-device.

For the clarity of the presentation, only one type of SAGU was introduced so far. In accordance to the SASO of the present invention, two distinct types of SAGU may be considered :

- ◆ a Radial SAGU - characterized by a core-flow being substantially perpendicular to the SAGU fins. This SAGU type is the one that was presented above, and illustrated in Figures 1a, 1b and 3, and further described in Figure-4a.

◆ a Tangential SAGU - characterized by a core-flow being locally substantially parallel to the SAGU fins, as shown in Figure-4b.

◆ a combination of Tangential and Radial SAGUs may be implemented in a single SASO-device, to fulfill different SASO-application requirements, and is also covered by the scope of the present invention, as long as the SASO-idea is maintained.

The definition of the physical dimensions of the Tangential SAGU are similar to the dimensions defined for the Radial SAGU, except for the gap "*d*" that becomes irrelevant. Two variables, the angle "α", and the distance "*f*", define the effective gap of the Tangential SAGU as shown in Figure-4b. Angle "α", defines the orientation of the fins with respect to the conduit wall, and does not have to be identical for all the fins. The dimension "*f*" is the shortest distance between the tip of a fin from one set to the opposing fin of the second set, as shown in Figure-4b. The basic idea of the present invention, generating an aerodynamic blockage by vortical flow patterns, is also dominant in the case of the Tangential SAGU, but the details may be different.

The essential difference between the Tangential SAGU and Radial SAGU, is the local wall-jet flow that is developed due to the core-flow motion that is parallel to the fin. Two significant aspects distinguish the Tangential SAGU flow-field from the Radial SAGU flow-field are the increased amplitude of the core-flow lateral wavy motion, and the relatively violent local impingement of the core-flow on the facing fins (see Figure-4a for a comparison with a Radial SAGU). Consequently, a different distribution of fluid-dynamic forces is generated upon the SASO-cell walls. These phenomena might significantly affect the main features of the present invention, namely, decreasing MFR and increasing ΔP.

Another distinct aspect of the Tangential SAGU in comparison with the Radial SAGU, is the change in fluid-dynamic resistance, when the fluid flow direction is reversed. It is due to the fact that while the Radial SAGU is of a "symmetric" nature with respect to flow direction, the Tangential SAGU has an "asymmetric" nature, in that respect. This tangential SAGU "dual behavior" may be beneficial, for instance, when a different fluid-dynamic resistance is required to inject or suck a fluid, in different operational stages, with different MFR requirements.

The second principle concept of the SASO of the present invention, and the SASO-technology is the *segmentation concept*. It states that specific engineering requirements can be fulfilled by a sequential arrangement of a plurality of SAGUs. Thus, a SASO-device can be configured with a plurality of identical type SAGUs, or by using a combination of more than one SAGU type. In other words, each SASO-device is characterized by a specific SAGU arrangement, the number of SAGUs, and the types of

SAGUs used. In this way the same basic components (SAGUs), can be re-utilized to design SASO-devices of different characteristics, to be implemented for a wide range of SASO-applications. Thus, the segmentation concept, included in the SASO-technology procedure of design, involves the selection the SAGU types and the optimal number of SAGUs to be used, and the SAGU axial arrangements along the specific SASO-device.

Therefore, any combination of SAGUs, in corporation with any configuration of the SASO-device inlet or outlet sections that are assembled together in the design, are all covered by the present invention. It is further noted that any variant of a SASO-device that is based substantially on the SASO-idea of vortical aerodynamic blockage including possible incorporation with various passive or active means, of various engineering disciplines, is covered by the scope of the present invention.

The present invention involves a wide variety of SASO-devices with distinct configurations. Some optional SASO-devices are hereafter described, without limiting the scope of the invention as defined by the appended Claims.

The basic SASO-device is the "SASO-tube" of rectangular cross section, illustrated in Figure-7a. It is essentially a three-dimensional SASO-device, where the third dimension of typical width "l2" is the "passive direction". Although the main fluid dynamic patterns are of a two-dimensional character, secondary flow effects of three-dimensional character may develop. The flow is of a three-dimensional nature when approaching the side walls (of the "passive" direction). As "l2" (Figure-7a) reaches a sufficiently small value, the flow becomes of significantly three-dimensional nature and viscous effects may significantly affect the SASO-tube performance. In particular it may cause an intensive decay of the vortical flow patterns, thus the aerodynamic blockage mechanism may be severely deteriorated. It is recommended that the size of "l2" should be, at least, similar to "l1" to practically avoid the above wall effects. Two side views and one top view of the basic two-dimensional configuration, are illustrated in Figure-7b. Lateral side view I shows the "active" dimension, with the two opposite fin arrays. Side view II shows a sectional view of both fin arrays appearing interlaced (this is of course not true, but the angle of view provides the interlacing effect). Top view III shows the first two opposite fins (4,5) at the inlet. As already mentioned, several fins of different laterally span distribution are optional, as shown in Figure-7c. Figure-6b illustrates several optional fins cross sections or fin profiles, The fin profile can be rectangular (212), sharp (211), curved (210) or of different fin's side surfaces (215). The arrays of fins can overlap (213) or not (212) or have no gap between them (211). The fins can be mounted perpendicularly to the SASO-conduit walls (212), or inclined with respect to the SASO-device conduit wall (214). The fin arrangement can provide a different behavior with respect to the direction of flow (214-215) or to be not sensitive to the flow direction (210-213). By using different fins, various

SASO-tube characteristics may be manipulated to fulfill specific requirements. This basic SASO-device consists of a predetermined number of identical SAGUs, as stipulated by SASO-technology procedure of design, depending on specific SASO- application requirements.

A modified SASO-device, namely a "SASO-slot", is defined in cases where "l2" is the lateral length of the fin along the passive direction is considerably larger then "l1", the second lateral direction, as illustrates in Figure-6a (222). Within this basic SASO-slot of stretched rectangular cross-section, the flow is essentially two-dimensional, as the lateral scale of the boundary layers and the resulting viscous effects, at the edges of the slot, is practically negligible in respect to "l2". Consequently, the one-dimensional lateral suppression (by the vortices) of the core-flow width, or, alternatively speaking, the aerodynamic blockage mechanism, may significantly improve.

A Directional SASO-device embodiments are given in Figures 7d, 7e and 7f, where the fluid-dynamic resistance becomes significantly different when the flow is reversed in direction. The asymmetric profile (215) and the inclined fins (214), see Figure-6b, are features of a directional SASO-device. Furthermore converging and diverging conduits (Figure-2b 203,204) establish a directional SASO-device. Additionally, Figure-7d is a "directional" SASO-device, where the span of the fins (14,15) is shortened gradually in a predetermined flow direction x. In this embodiment the core-flow is divergent in direction x, or convergent if the flow direction is reversed, as the aerodynamic resistance is not similar in both directions. Figure-7e shows a different "directional" SASO-device, where one surface of the fin (14,15) is, for example, flat and the opposite side of the fin is curved. In this case the characteristics of the vortical flow patterns and the core-flow are manipulated differently, and the aerodynamic resistance varies, when the flow changes its direction. In fact, a SASO-device based on Tangential SAGU is a typical example of a Directional SASO-device. Figure-7f show different "directional" SASO-device, where the pitch or the distance between two consecutive fin changed gradually in a predetermined flow direction x.

The examples discussed so far are all dealing with open curved vortex lines (having two ends). A special case of the SASO-slot is the annular SASO-slot, shown in Figure-8, which exhibits the possibility of creating two arrays of closed-loop vortices (in this case, two arrays of vortex-rings). Figure-8a illustrates an annular SASO-slot (50), having two opposite ring-shaped fins arrays (the top two fins are shown in Figure-8a, and see also fins (53, 54) in Figure-8b), where the annular SASO-slot conduit has an internal wall (52) of radius r_1, and an external wall (51) of radius r_2. as shown in Figure-8b. Figure-8b illustrates a sectional view of the annular SASO-slot, where two arrays of ring-shaped fins (53,54) are positioned within the internal walls (51, 52) of the annular conduit. The

vortical pattern formed in an annular SASO-slot is in the form of two arrays of vortex-rings (55, 56). Note that in this configuration the core-flow suppression by the vortex-rings is also of a one-dimensional character.

A different type of a SASO-device, of a three dimensional character, is presented in Figure-9a. This type of a SASO-device has a conduit of lateral rectangular cross section (Figure-9b) with "L" shaped fins (14,15), that are consecutively located at opposing corners. Figure-9c depicts a longitudinal cross section view of the first two fins (segment U and segment D) of the SASO-device. In this three dimensional type of SASO-device, the core-flow is laterally suppressed by the vortices in a two dimensional manner. Such suppression is the most significant issue of three dimensional variants of SASO-device, where in a two dimensional SASO-device variants, the core-flow suppression is of one dimensional character. As a result of the two dimensional lateral core-flow suppression, the aerodynamic blockage efficiency of three dimensional SASO-device configuration is expected to improve. Another similar alternative is shown in Figure-9d, where "U" shaped fins (14,15) are mounted within a conduit having a polygon cross-section.

Figure-10 illustrates a longitudinal cross section view of a SASO-device comprising a conduit (40), here possessing circular lateral cross section, with a single fin (41) presenting an internal helical structure. It is in fact one helical fin, optionally provided with barriers (42) distributed along the device to enforce flow separation and prevent a natural selection of a helical flow motion that may be triggered at specific combinations of geometrical parameters. Note that the presence of such barriers is not essential, but may improve flow separation. This is a three dimensional SASO-device type where the core-flow is being laterally suppressed from all directions in a two dimensional circumferential manner by the helical vortex developed. Therefore, such a configuration of SASO-device is essentially an efficient variant enhancing aerodynamic blockage effect. Furthermore, this configuration offers a dual passage for the fluid flow. The flow can separate from the fin and move in the central passage, or move in a circumferential direction along the fin. The geometrical design, with or without barriers, is aimed to make the flow chose the first route, and separate from the fin, filling the helical cavity behind the fin with a helical vortex, thus obtaining similar pattern as the SASO-tube described before. However, if a contamination of any kind is stuck in the central passage, physically blocking the flow locally, this type of a SASO-tube offers an alternative passage - the helical route - to overcome this obstacle locally, and then resume the central separation route, in a self adaptive manner or forced by the next barrier (if it exists). This dual passage character is of great importance since it offers a SASO-device with its advantages, that is "almost free" of mechanical blockage, and can thus operate well in applications where severe contamination environment exists. Preferably said passage is not more than 30% of the

adjacent lateral width of said conduit. Optionally, both fin ends may be provided with extruding rims, projecting substantially normal to the fin surface, used as a seat to hold the helical vortex at its both ends.

The internal features of SASO-devices (such as the fin construction, size, texture and shape, etc.) apply accordingly to the helical fin SASO-device too.

A totally different SASO-device is the "SASO-open-channel" shown in Figure-11a, where the to set of fins (14,15) are vertically mounted with respect to gravity. It is an open channel containing water (or any other liquid), where the difference in the water level, Δh=h1-h2, h1 being the water level at the inlet (2), and h2 being the water level at the outlet (3), as shown in Figure-11b, replaces the external pressure drop. Here the aerodynamic blockage is established by a set of vortices that are developed behind each fin, where the vortices virtual axis starts at the bottom of the water channel and ends at the contact layer between the fluid and the atmospheric. Figure-11c illustrates the possibility to obtain self-adaptive response with respect to water level. When the fins (60) present a uniform width to water level, changes in the water level are less dominant compared with the case where the fins vary vertically, having a curved span distribution where as the water level decreased, the blockage effect decays. The fins (62) exhibit also high and low level character.

When a plurality of SASO-open-channels are combined in parallel, an elongated structure - a breakwater - is constructed as shown in Figure-12. In this case, the fins vertical length correspond to the sea depth. Such a low-weight porous breakwater can straggle against the sea waves and the sea underwater currents, in a self adaptive manner by implementing the aerodynamic blockage mechanism, but it also allows the migration of sand through the breakwater construction, especially out of the harbor.

SASO-device can also be incorporated in a heat exchanger as shown in Figure-13 where a plurality of SASO-conduits mount inside a heat-exchanger. Here Two mechanisms of heat transfer are involved (a) the vortices enhanced the mixing performance of the heat-exchanger and (b) the core-flow is responsible for transferring the heat away. Therefore it is expected that the optimal gap between the to opposite arrays of fins will be relatively large for such a SASO-application, so as to balance the two heat exchange mechanism.

The following discussion refers generally to the present invention. It is possible to attach two or more SASO-devices together, to establish a new SASO-device of improved characteristics. This attachment can be made in various ways, for example, two or more SASO-devices can be attached in a sequence, or be attached in parallel. A plurality of identical or different SASO-devices can be arranged in a one-dimensional manner along

an elongated embodiment or be arranged in a manner on a surface of any geometrical shape. In particular, flat surfaces and cylindrical surfaces are of great importance from practical point of view. As long as at least one of the plurality of SASO-devices exhibits the vortical aerodynamic blockage effect, it complies with the SASO-technology and SASO-idea, and is therefore covered by the scope of the present invention.

Without derogating the generality, optional applications of various SASO-devices are hereafter discussed.

Numerous flow control applications in industry, medicine. consumer household, etc. require simple and low-cost solutions to control or limit the MFR. In many cases, when a precise MFR setting is not an important requirement, and as long as the MFR remains within tolerable limits, the use of the sophisticated means of control is expensive or redundant. In these cases a SASO-device can serve to keep the flow within the desired limits. A SASO-device can serve in vacuum conditions or in moderate and high pressure conditions. It can be used in cases where suction or injection are involved. In particular, when a system must be equipped with a large number of stand-alone MFR control elements, the use of a plurality of simple, low-cost and maintenance-free control means, such as SASO-devices, becomes a necessity. SASO-devices can also serve in many pressure control applications, to regulate or sustain the pressure within a required domain. In particular, SASO-devices can be used to control fluid induced forces.

The SASO-device mechanism of vortical aerodynamic blockage is essentially non-viscous. Therefor as long as the Re (Reynolds number) is of an order of 10 or more - as long as viscous effects do not dominate the flow - the aerodynamic blockage mechanism controls the flow through the SASO-conduit. Practically speaking, (a) the SASO-device typical size can be of an order of 1 mm (or less, as long as the fluid motion velocity is high enough) for small scale applications, (b) the SASO-device typical size can be of an order of 1 or 10 cm for moderate scale applications, and (c) the SASO-device typical size can be of an order measured in terms of meters for large scale applications. SASO-technology can be implemented both for close conduits and open channels.

SASO-technology can be useful, for applications that involve any kind of liquids or gases. It can also be used to control multi-phase flow or granular motion. Some SASO-device variants may work in a dual-functioning mode. Thus a dual-functioning SASO-device variant can exhibits a different aerodynamic resistance when the fluid motion is reversed or dramatically changed. The SASO-device is of a larger physical scale with respect to its dynamic scale that is much smaller according to the aerodynamic blockage. Therefore the risk of particle contamination blockage is significantly reduced. Some SASO-device embodiments exhibit dual-passage character (see Figure-10). Thus a dual-passage SASO-device can perform in a severe operational conditions, where even if

contamination blocks the conduits, the flow adaptively directs itself locally to the second optional flow route.

Beside the direct applications of controlling MFR and/or ΔP, the scope of the present invention includes various applications based on fluid induced force where a SASO-device is used for the purposes of force and/or positioning control. The present invention is also applicable in hydraulic and pneumatic systems, air-bearings and air-bed systems.

Another practical application of the present invention is to use the vortical flow pattern itself and it intensive interaction with the SASO-conduit walls for heat-transfer enhancement.

The SASO-device of the present invention may serve in various applications and may characteristically possess three working modes:

1. When closed at its inlet it may generate suction forces, or transfer pressure conditions from the outlet to the inlet.
2. When open it controls the through-flow, employing the vortical aerodynamic blockage mechanism, as described above
3. When almost closed, it may beneficially employ the dramatic changes imposed on the aerodynamic blockage, as it is about to collapse.

It should be clear that the description of the embodiments and the attached Figures set forth in this specification serve only for a better understanding of the invention, without limiting its scope as covered by the following Claims.

It should also be clear that adjustments or amendments to the attached Figures and the above described embodiments, made by a person in the art, after reading the present specification, would still be covered by the following Claims.

CLAIMS

1. A flow control device comprising a fluid conduit, having an inlet and outlet, said conduit provided with at least three fins mounted on the internal wall of said conduit wherein two of said three fins and a portion of said conduit internal wall define a cavity and the third of said three fins positioned opposite said cavity;

whereby when fluid flows through said conduit at least one substantially stationary vortex is formed in said cavity said vortex existing at least temporarily during said flow thus forming an aerodynamic blockage allowing a central core-flow between the vortex and the tip of said third fin and suppressing the flow in a one-dimensional manner, thus limiting the mass flow rate and maintaining a substantial pressure drop within the conduit.

2. A flow control device comprising a fluid conduit, having an inlet and outlet, said conduit is provided with a plurality of fins mounted on the internal wall of said conduit said fins arranged in two arrays substantially opposite each other;

wherein each of the fins of either one of said fin arrays excluding the fin nearest to the inlet and the fin nearest to the outlet of said conduit is positioned substantially opposite one of a plurality of cavities each cavity defined between two consecutive fins of one of said arrays of fins and a portion of said conduit internal walls wherein said two opposing fin arrays are arranged asymmetrically;

whereby when fluid flows through said conduit a plurality of vortices are formed within said cavities one vortex in a cavity said vortices existing at least temporarily during said flow thus forming an aerodynamic blockage allowing a central core-flow between said vortices and the tips of said fins suppressing the flow in a one-dimensional manner, thus limiting the mass flow rate and maintaining a substantial pressure drop within the conduit.

3. The device as claimed in Claim 2 wherein said fins are L-shaped so as to allow a thin core-flow suppressed in a two-dimensional manner by said vortices.

4. The device as claimed in Claim 2 wherein said fins are U-shaped so as to allow a thin core-flow suppressed in a two-dimensional manner by said vortices.

5. The device as claimed in Claim 2 wherein said conduit follows a straight path.

6. The device as claimed in Claim 2 wherein said conduit follows a tortuous path.

7. The device as claimed in Claim 2 wherein said conduit cross-section is substantially rectangular.

8. The device as claimed in Claim 2 wherein said conduit cross-section is substantially polygonal.

9. The device as claimed in Claim 2 wherein said conduit cross-section is substantially circular.

10. The device as claimed in Claim 2 wherein the downstream distribution of said conduit cross-section area is uniform.

11. The device as claimed in Claim 2 wherein the downstream distribution of said conduit cross-section area is divergent.

12. The device as claimed in Claim 2 wherein the downstream distribution of said conduit cross-section area is convergent.

13. The device as claimed in Claim 2 wherein said fins are substantially perpendicular to said internal wall of the conduit.

14. The device as claimed in Claim 2 wherein said fins are inclined with respect both to the general core-flow direction of motion and to the conduit internal walls.

15. The device as claimed in Claim 2 wherein the average thickness of each of said fins is smaller in order compared to the distance between said fin and the next consecutive fin of the same fin array.

16. The device as claimed in Claim 2 wherein the fin cross-section is substantially rectangular.

17. The device as claimed in Claim 2 wherein the fin cross-section is substantially trapezoidal.

18. The device as claimed in Claim 2 wherein the fin cross-section is substantially concave at least on one side.

19. The device as claimed in Claim 2 wherein the distance between two consecutive fins is constant along the conduit.

20. The device as claimed in Claim 2 wherein the distance between two consecutive fins varies along the conduit.

21. The device as claimed in Claim 2 wherein the span of each of said fins is uniform along the conduit.

22. The device as claimed in Claim 2 wherein the span of said fins varies along the conduit.

23. The device as claimed in Claim 2 wherein the span of said fin is laterally uniform.

24. The device as claimed in Claim 2 wherein the span of said fin laterally varies.

25. The device as claimed in Claim 2 wherein the tips of said fins are sharp.

26. The device as claimed in Claim 2 wherein the tips of said fins are blunt.

27. The device as claimed in Claim 2 wherein the tips of said fins are curved.

28. The device as claimed in Claim 2 wherein each of said fins substantially blocks half of the conduit lateral width.

29. The device as claimed in Claim 2 wherein the two opposite fin arrays do not

overlap.

30. The device as claimed in Claim 2 wherein the two opposite fin arrays overlap.

31. The device as claimed in Claim 2 wherein the ratio between the fin span and the gap between that fin and a consecutive fin of the same array of fins is in the range of 1:1 to 1:2.

32. The device as claimed in Claim 31 wherein the said ratio is about 1:1.5.

33. The device as claimed in Claim 2 wherein the absolute value of the gap between the virtual plane connecting the fin tips of one of said two opposite fin arrays and the virtual plane connecting the fin tips of the second of said two opposite fin arrays is of smaller order than the lateral width of said conduit.

34. The device as claimed in Claim 33 wherein said absolute value of said gap is not more than 20% of the adjacent lateral width of said conduit.

35. The device as claimed in Claim 2 wherein the size of each of said cavities is slightly smaller than the integrally defined natural scales associated with the vorticity of the vortex formed inside said cavity.

36. The device as claimed in Claim 2 wherein the said conduit passive dimension defined as the dimension substantially parallel to said vortices virtual axes and substantially perpendicular to said core-flow motion is in the order of the fins span.

37. The device as claimed in Claim 36 wherein said passive dimension is substantially larger than the other lateral dimension of the conduit that is substantially perpendicular to both the vortex axis and to the core-flow motion.

38. The device as claimed in Claim 36 wherein said passive dimension follows a close substantially annular route.

39. The device as claimed in Claim 2 wherein when Reynolds Number is increased inside said conduit further secondary vortices are formed.

40. The device as claimed in Claim 2 wherein said core-flow downstream motion is substantially sinusoidal.

41. The device as claimed in Claim 40 wherein the sinusoidal core-flow strongly interacts with the fins by local impingement of the core flow with the surfaces of the fins facing its motion.

42. The device as claimed in Claim 2 wherein when Reynolds Number is increased inside said conduit said core-flow breaks down locally and frequently generates unsteady secondary vortices intensively interacting with the core-flow or impinging on the surface of the facing fin.

43. The device as claimed in Claim 2 wherein it used for controlling the transfer of fluids flowing through the device.

44. The device as claimed in Claim 2 wherein it used for generating fluidically induced

forces.

45. The device as claimed in Claim 2 wherein it is incorporated in a heat exchanger.

46. The device as claimed in Claim 2 wherein it used as a silencer.

47. The device as claimed in Claim 2 wherein said conduit when closed at its inlet generates suction forces or transfers vacuum conditions from the outlet to the inlet.

48. The device as claimed in Claim 2 wherein said conduit when closed at its outlet generates pressure forces or transfers pressure conditions from the inlet to the outlet.

49. The device as claimed in Claim 2 wherein when said conduit outlet is almost closed it employs dramatic changes imposed on the aerodynamic blockage as it is about to collapse.

50. The device as claimed in Claim 2 wherein said conduit is an open channel of water said channel has an inlet at a higher level water reservoir and an outlet at a lower level water reservoir where said plurality of fins are positioned substantially vertical with respect to gravity and also substantially perpendicular to the water direction of motion thus vertical vortices are formed between the floor of said channel and the contact-layer between the water and the air, whereby the flow of water is controlled by said aerodynamic blockage.

51. The device as claimed in Claim 49 wherein the fins span varies parallel to said vortices, thus obtaining changing hydrodynamic blockage effects with respect to the water level.

52. The device as claimed in Claim 49 wherein a plurality of said channels are combined together in parallel to act as a breakwater with the inlets directed to the open sea and the outlets directed to the land side whereby allowing the migration of sand through said breakwater.

53. A flow control device comprising a conduit having an inlet and an outlet said conduit is provided with a helical fin mounted on the internal wall of said conduit thus a helical cavity is formed defined by said helical fin and said internal wall;
wherein when a fluid flows through said conduit a helical vortex is formed within said helical cavity said helical vortex exists at least temporarily during said flow thus forming an aerodynamic blockage allowing a central core-flow between said vortex and the tip of said helical fin and suppressing the flow in a two-dimensional manner, thus limiting the mass flow rate and maintaining a substantial pressure drop within the conduit;

whereby said core flow flows through a central passage defined by the helical fin internal edge and may locally bypass an obstruction in said central passage by following the helical passage adjacent the helical fin.

54. The device as claimed in Claim 53 wherein at least one barrier of a plurality of barriers is mounted substantially normally to said helical fin surface thus locally blocking the helical path to prevent the flow from following the helical path and thus said helical vortex locally splits by said barriers to at least two fragments.

55. The device as claimed in Claim 53 wherein at least one barrier out of two barriers is mounted substantially normally to the fin surface on one of the two ends of said helical fin to act as anchorage for said helical vortex.

56. The device as claimed in Claim 53 wherein said conduit follows a straight path.

57. The device as claimed in Claim 53 wherein said conduit follows a tortuous path.

58. The device as claimed in Claim 53 wherein said conduit cross-section is substantially circular.

59. The device as claimed in Claim 53 wherein said conduit cross-section is substantially rectangular.

60. The device as claimed in Claim 53 wherein said conduit cross-section is substantially polygonal.

61. The device as claimed in Claim 53 wherein the downstream distribution of said conduit cross-section area is uniform.

62. The device as claimed in Claim 53 wherein the downstream distribution of said conduit cross-section area is divergent.

63. The device as claimed in Claim 53 wherein the downstream distribution of said conduit cross-section area is convergent.

64. The device as claimed in Claim 53 wherein said helical fin is substantially perpendicular to said internal wall of the conduit.

65. The device as claimed in Claim 53 wherein said helical fin is inclined with respect both to the general core-flow direction of motion and the to conduit wall.

66. The device as claimed in Claim 53 wherein the said helical fin thickness is smaller in order with comparison to said helical fin pitch.

67. The device as claimed in Claim 53 wherein the helical fin cross-section is substantially rectangular.

68. The device as claimed in Claim 53 wherein the helical fin cross-section is substantially trapezoidal.

69. The device as claimed in Claim 53 wherein the helical fin cross-section is substantially concave at least on one side.

70. The device as claimed in Claim 53 wherein the said helical fin pitch is constant

along the conduit.

71. The device as claimed in Claim 53 wherein said helical fin pitch varies along the conduit.

72. The device as claimed in Claim 53 wherein the span of said helical fin is uniform.

73. The device as claimed in Claim 53 wherein the span of said helical fin varies along the conduit.

74. The device as claimed in Claim 53 wherein the tip of said helical fin is sharp.

75. The device as claimed in Claim 53 wherein the tip of said helical fin is blunt.

76. The device as claimed in Claim 53 wherein the tip of said helical fin is curved.

77. The device as claimed in Claim 53 wherein said helical fin span is substantially half of the said conduit lateral width.

78. The device as claimed in Claim 53 wherein the ratio between the helical fin span and the helical fin pitch is in the range of 1:1 to 1:2.

79. The device as claimed in Claim 78 wherein the said ratio is about 1:1.5.

80. The device as claimed in Claim 53 wherein the central passage defined by the helical fin tip is of smaller order in comparison with the hydraulic diameter of said conduit.

81. The device as claimed in Claim 80 wherein said gap is not more than 30% of the adjacent lateral width of said conduit.

82. The device as claimed in Claim 53 wherein the size of said helical cavity is slightly smaller than the integrally defined natural lateral scales associated with the vorticity of the said helical vortex.

83. The device as claimed in Claim 53 wherein when Reynolds Number is increased inside said conduit further secondary vortices are formed.

84. The device as claimed in Claim 53 wherein the core-flow strongly interacts with said helical fin by local impingement with the surface of the helical fin facing its motion.

85. The device as claimed in Claim 53 wherein when Reynolds Number is increased inside said conduit said core-flow breaks down locally and frequently generates unsteady secondary vortices, intensively interacting with the core-flow or impinging on the facing fin.

86. The device as claimed in Claim 53 wherein it used to transfer fluids.

87. The device as claimed in Claim 53 wherein it used to generate fluidically induced forces.

88. The device as claimed in Claim 53 wherein it used as a silencer.

89. The device as claimed in Claim 53 wherein said conduit when closed at its inlet generates suction forces or transfers vacuum conditions from the outlet to the inlet.

90. The device as claimed in Claim 53 wherein said conduit when closed at its outlet generates pressure forces or transfers pressure conditions from the inlet to the outlet.

91. The device as claimed in Claim 53 wherein when said conduit outlet is almost closed it employs dramatic changes imposed on the aerodynamic blockage as it is about to collapse.

92. A flow control method for the control of flow of fluids from higher energy reservoir to lower energy reservoir, said method comprising providing at least one solid partial blockage and at least one complementary vortical flow structure in a conduit through which a fluid flows whereby said solid partial blockage and said complementary vortical flow structure act as an aerodynamic blockage.

93. A flow control device substantially as described in the above specification, accompanying Figures and appending Claims.

94. A flow control method substantially as described in the above specification, accompanying Figures and appending Claims.

Fig. - 1a

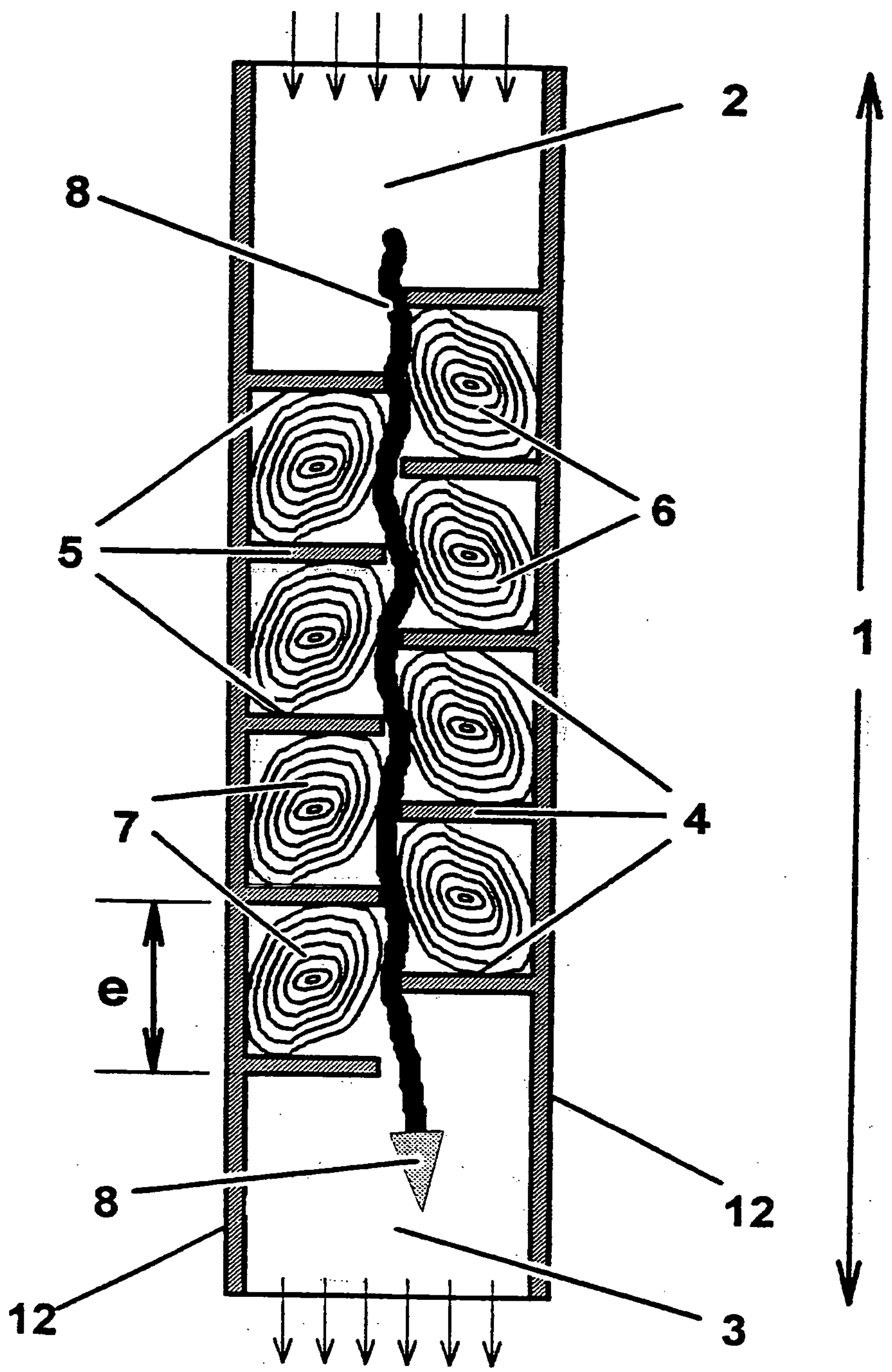


Fig. - 1b

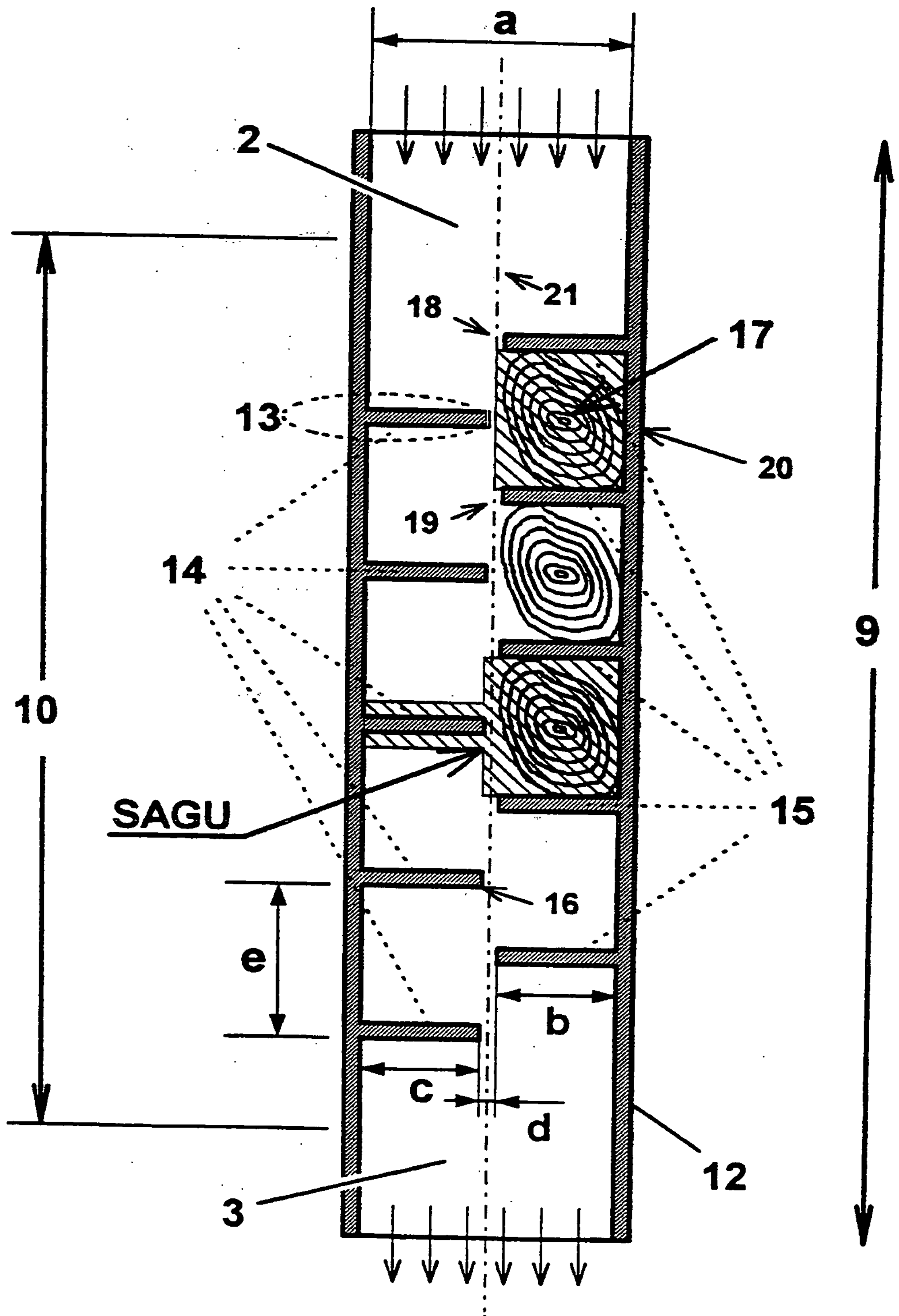


Fig. - 2a

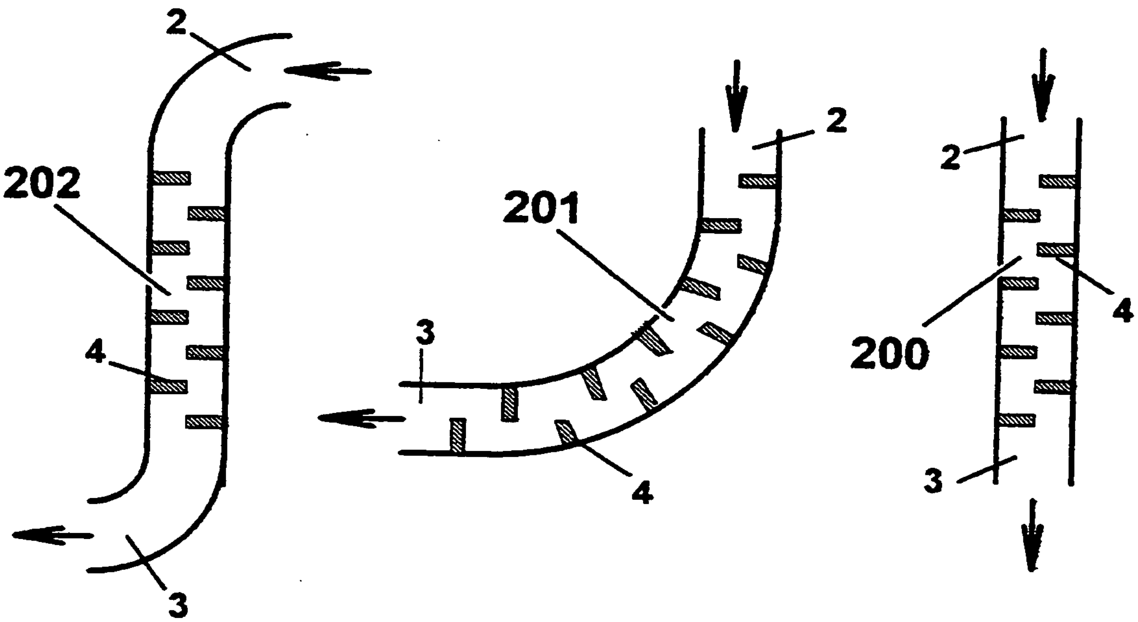


Fig. - 2b

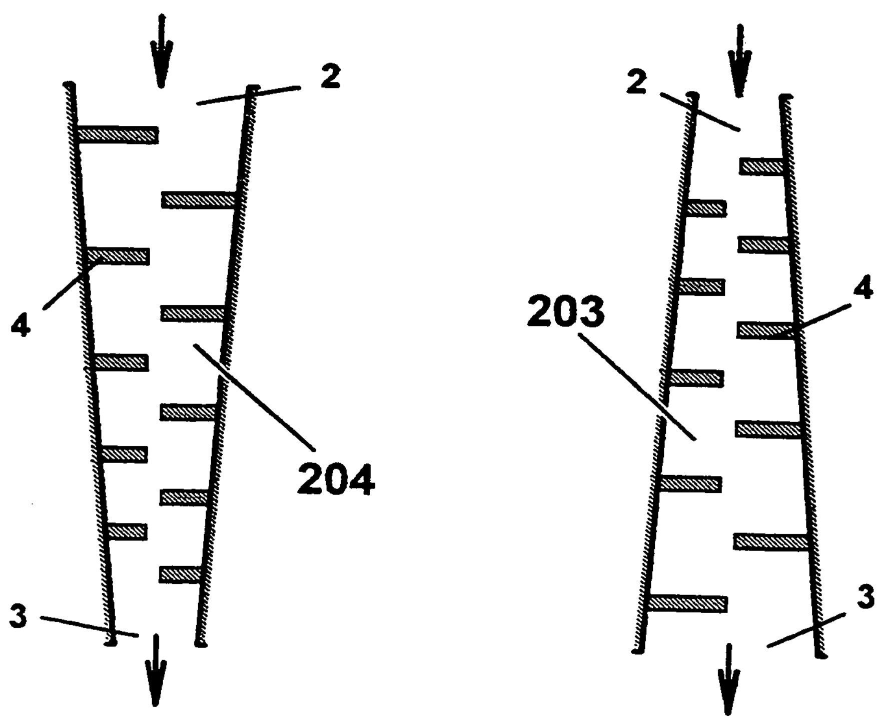


Fig. 3a

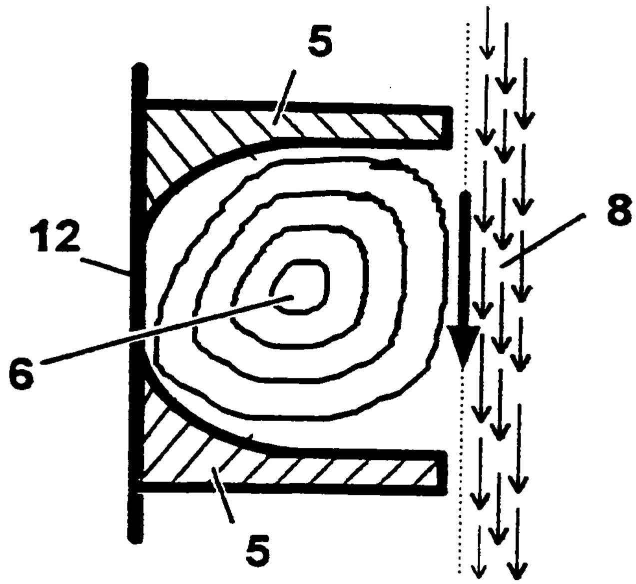


Fig. 3b

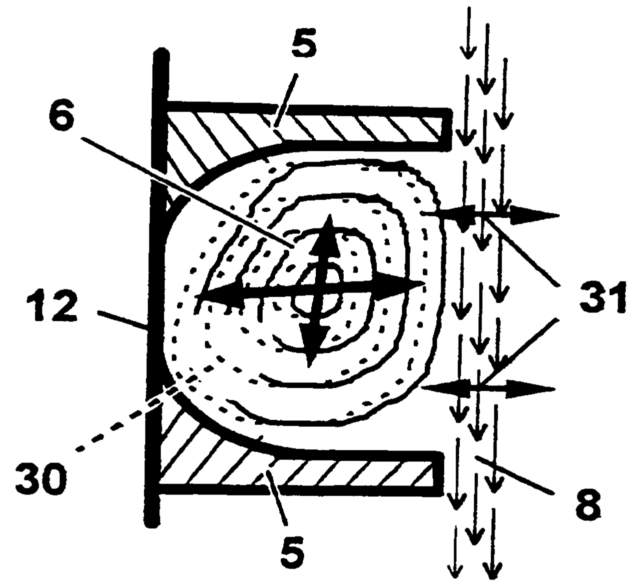


Fig. 3c

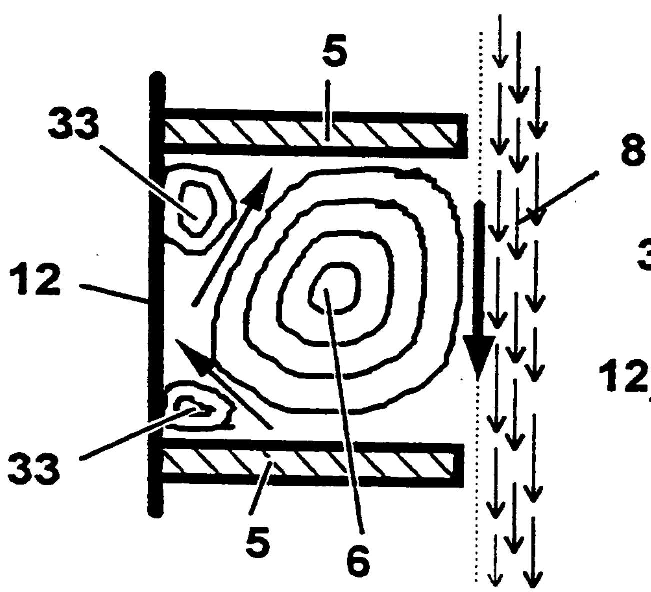


Fig. 3d

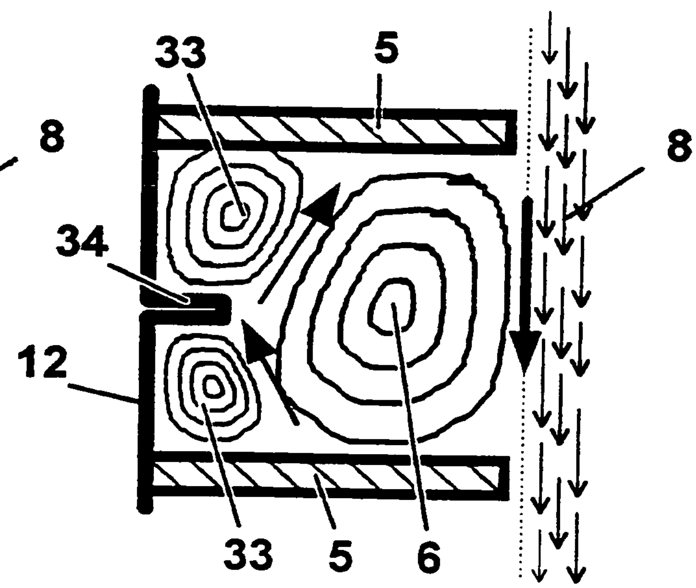


Fig. 3e

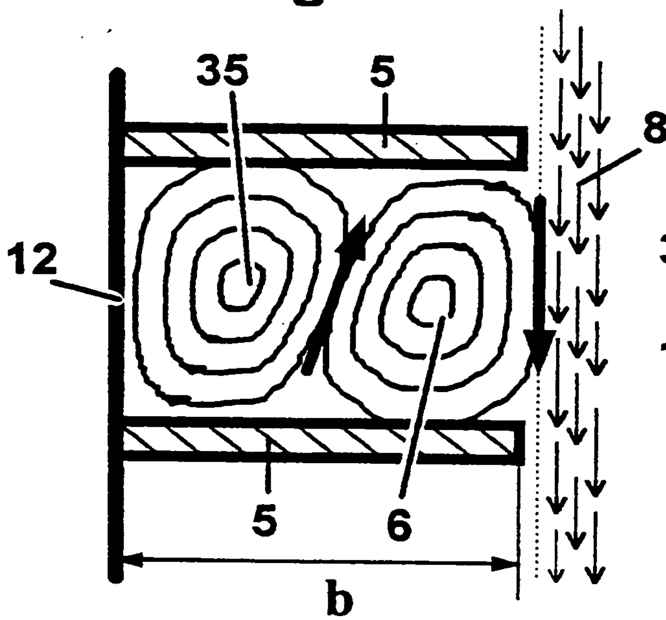


Fig. 3f

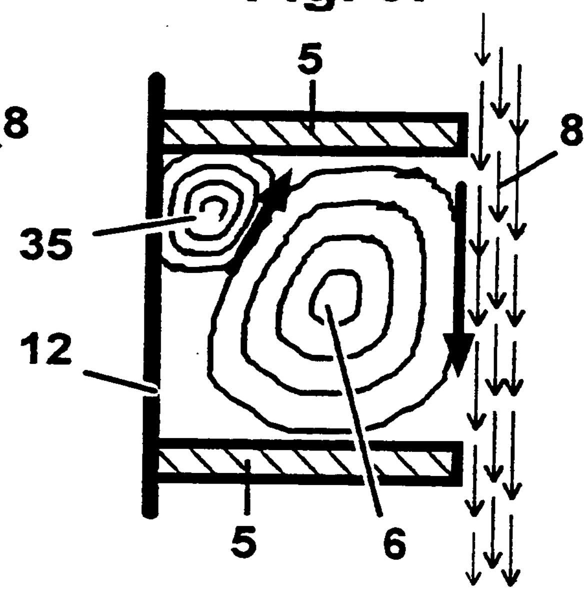


Fig. 3g

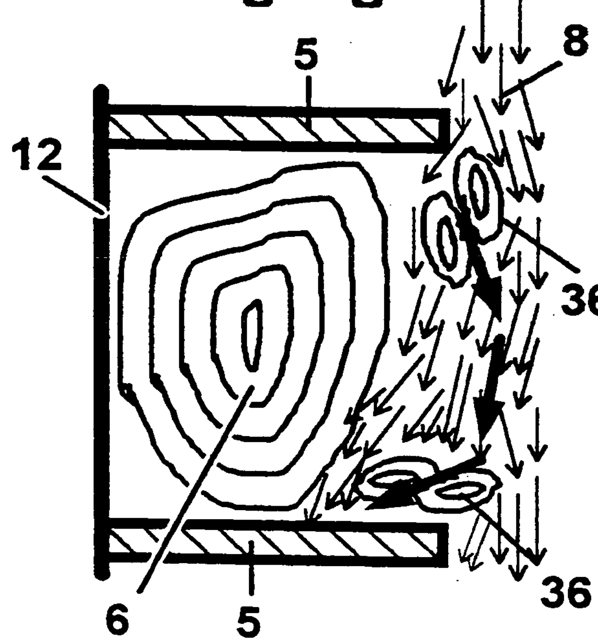


Fig. 3h

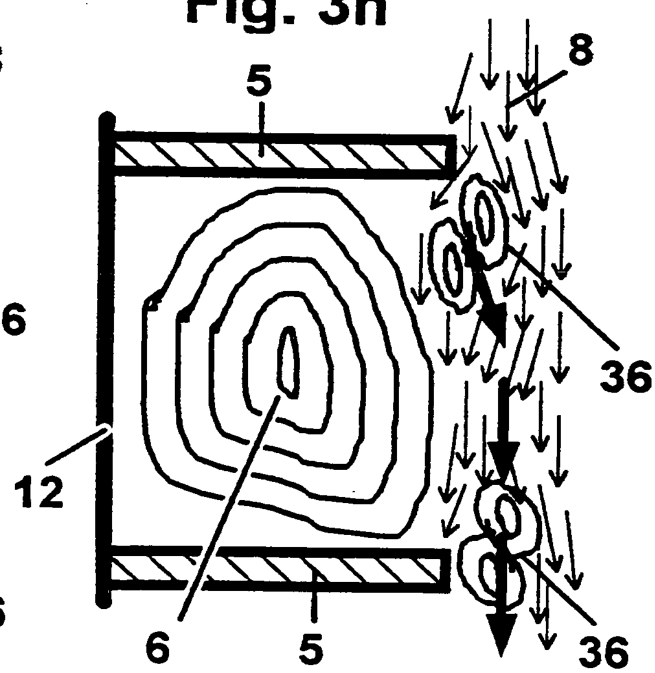


Fig. 4a

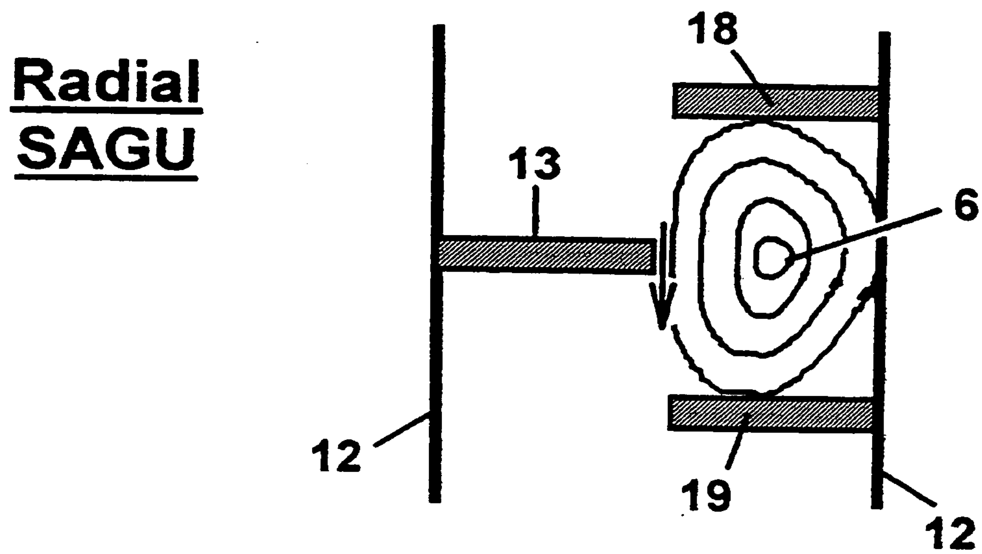


Fig. 4b

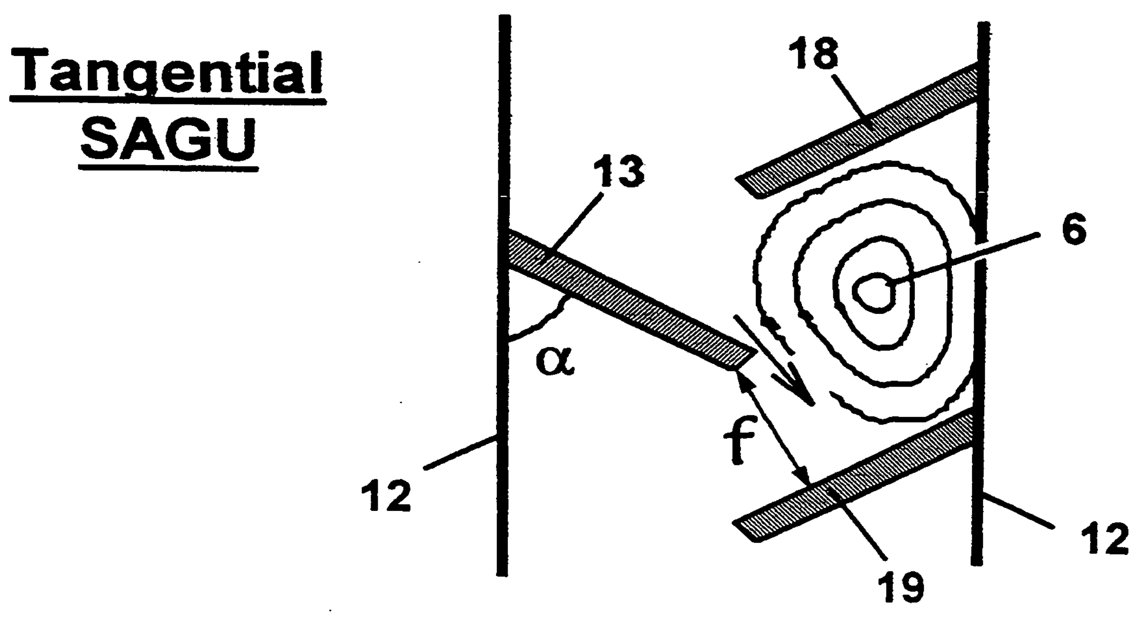


Fig. 5a

Fig. 5b

Fig. 5c

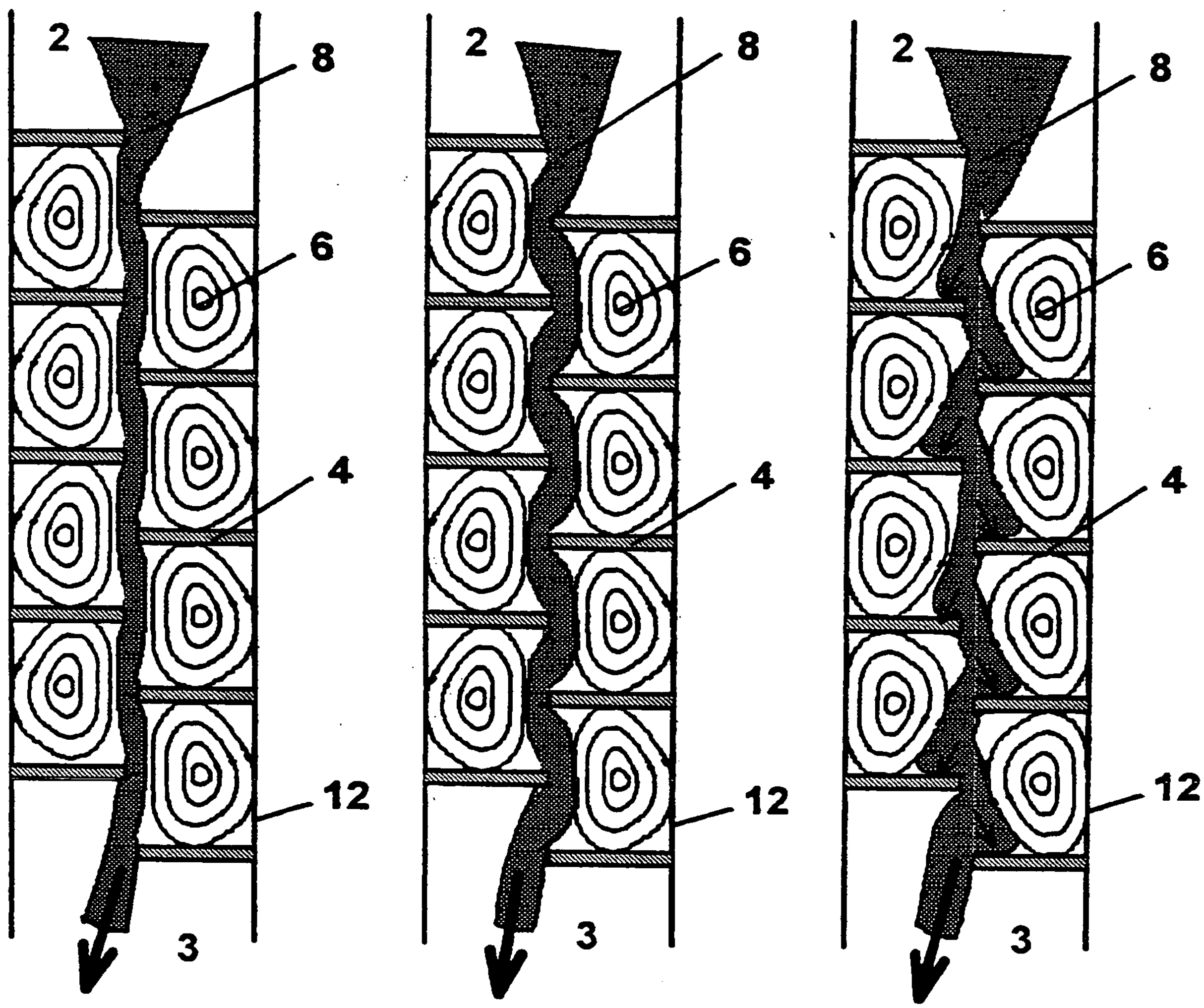


Fig. 6a

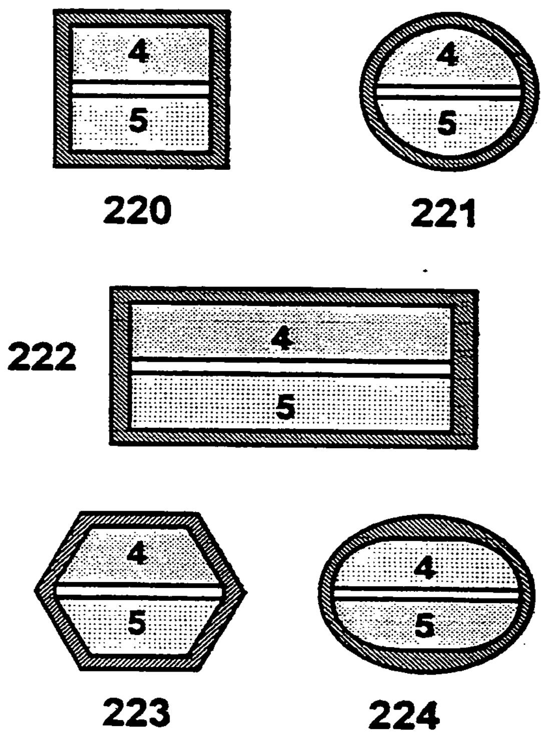


Fig. 6b

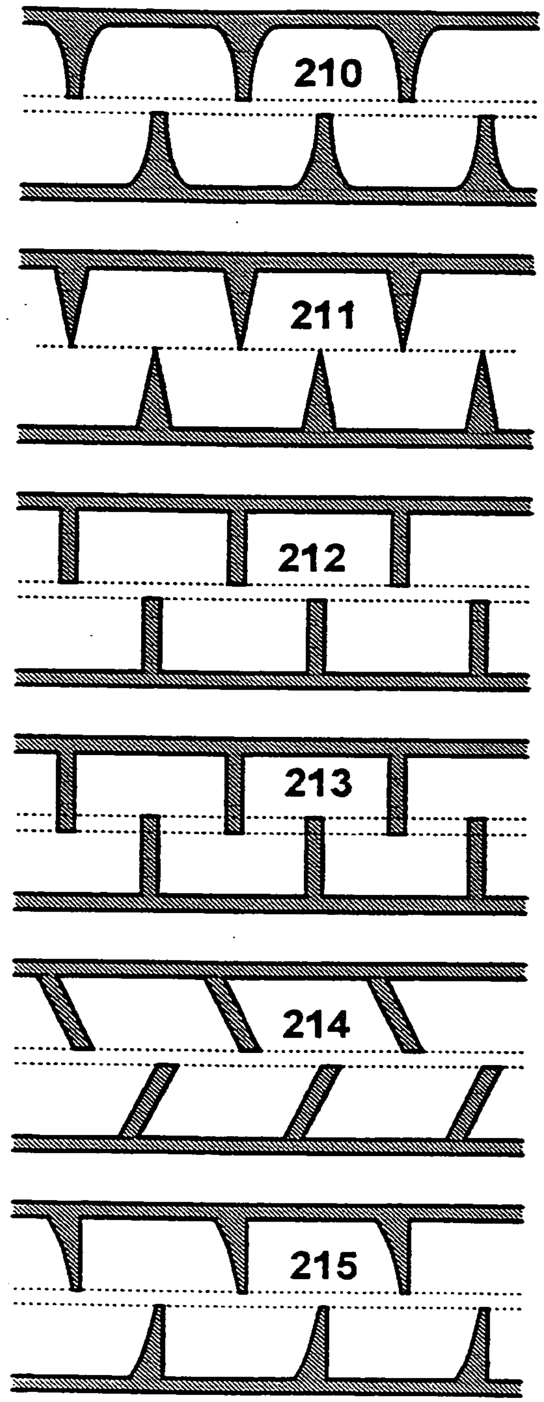


Fig. 6c

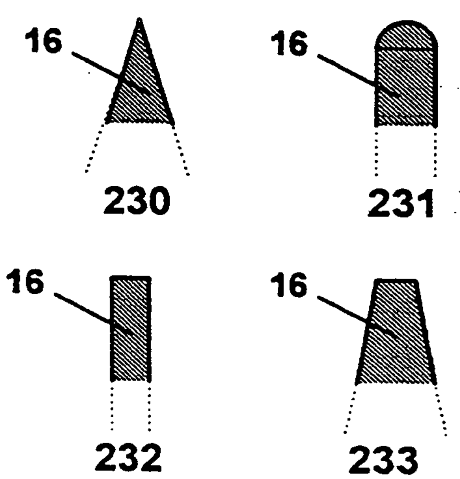


Fig. 7a

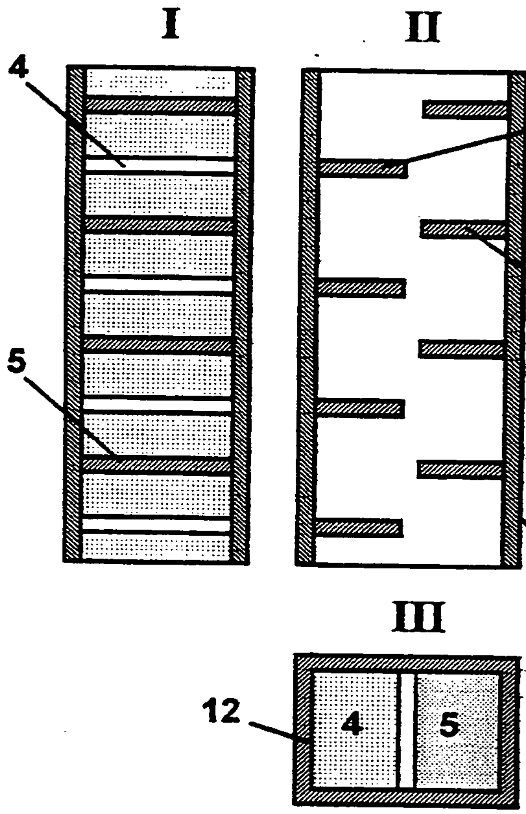


Fig. 7b

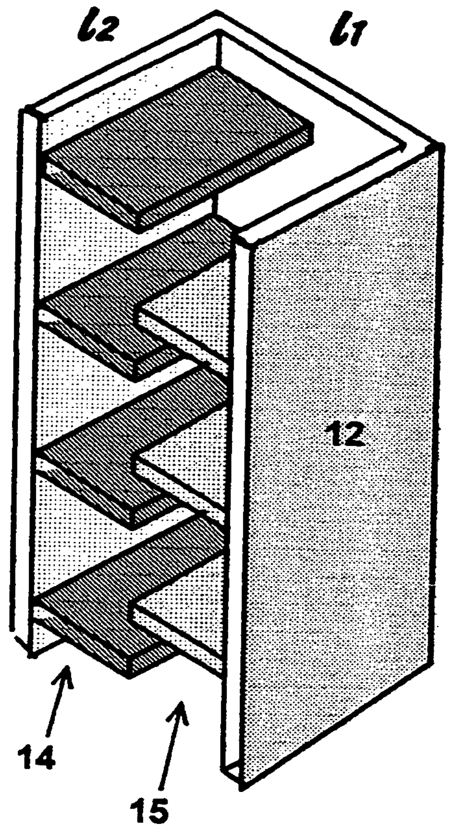


Fig. 7c

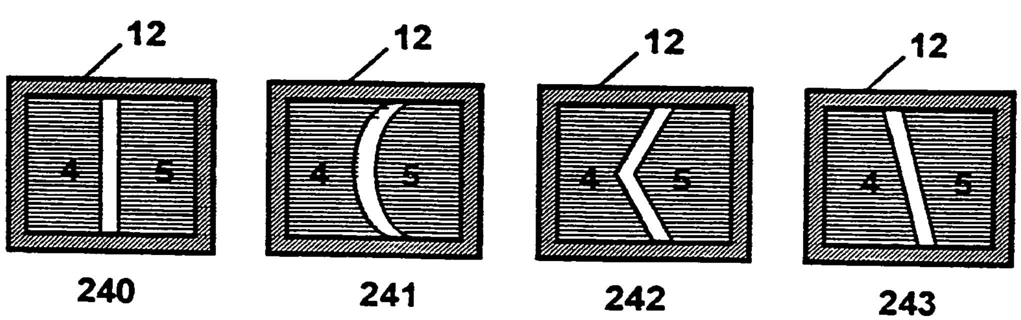


Fig. 7d

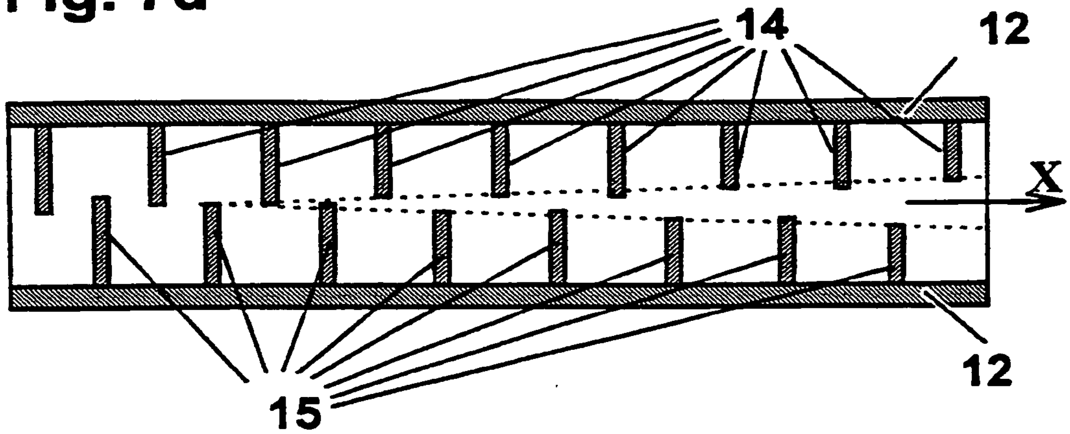


Fig. 7e

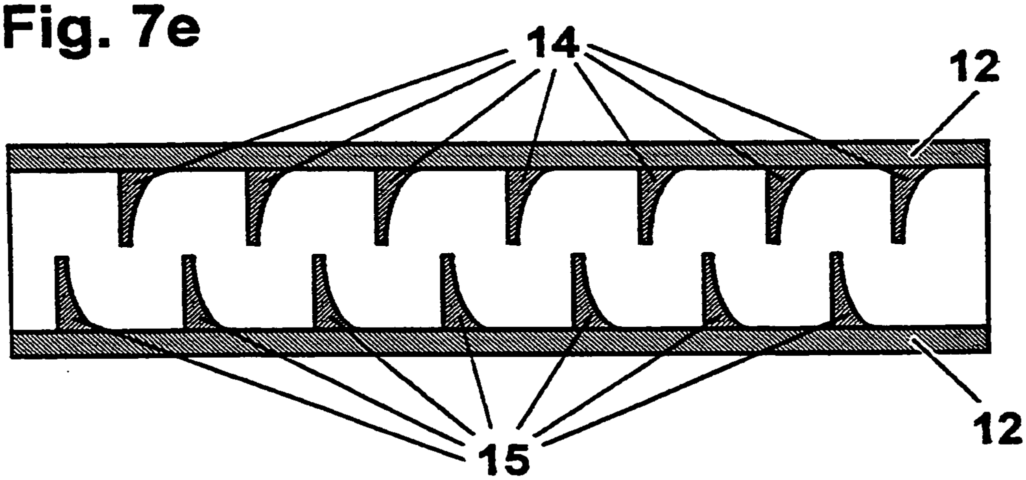


Fig. 7f

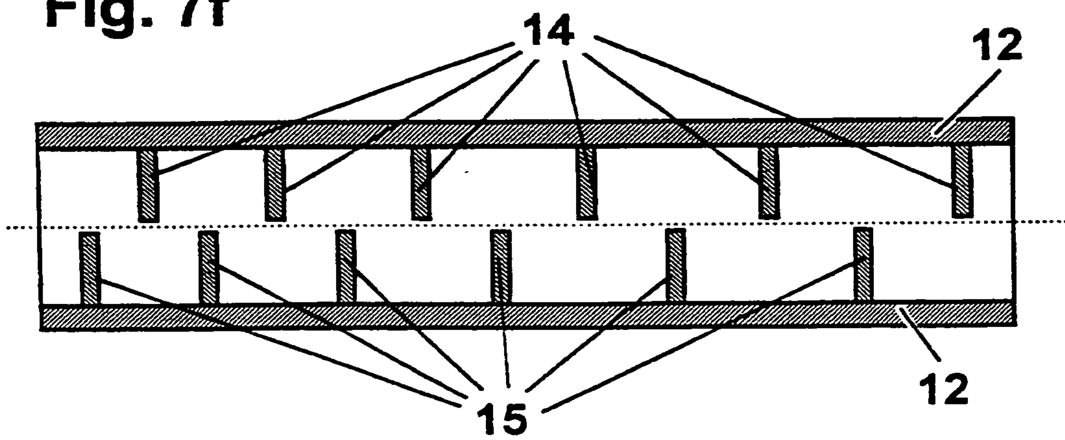


Fig. 8a

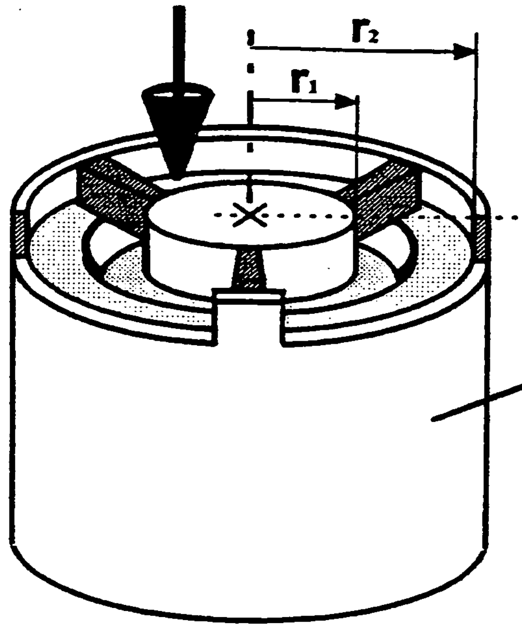


Fig. 8b

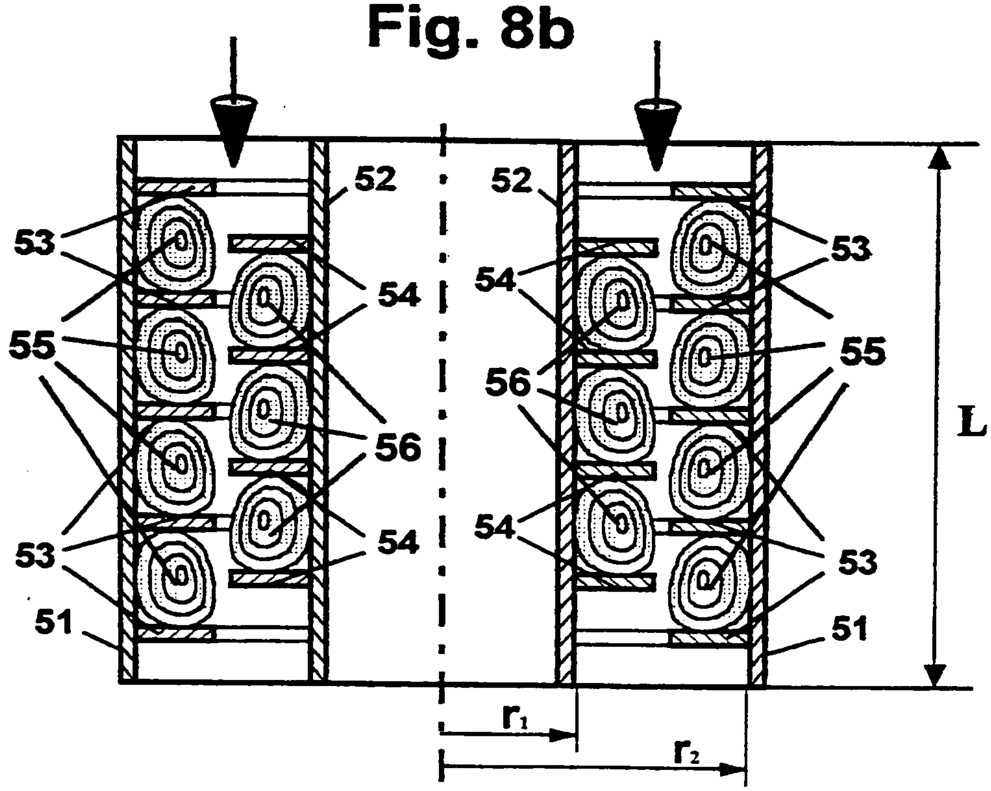
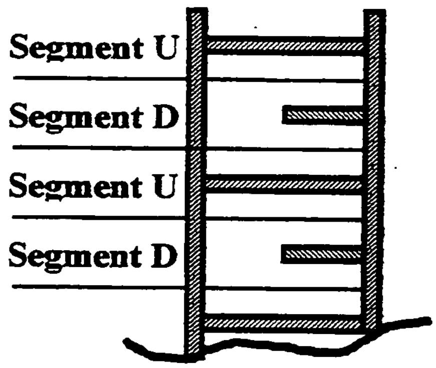


Fig. 9b



Cross Section AB

Fig. 9c

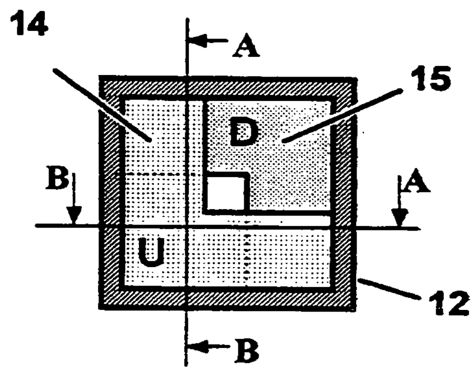


Fig. 9d

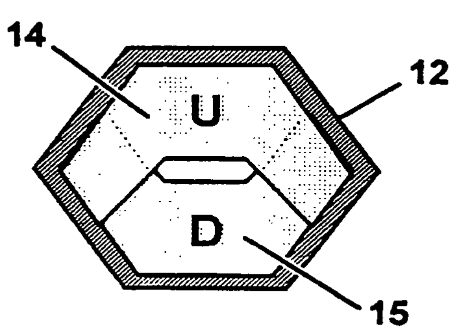


Fig. 9a

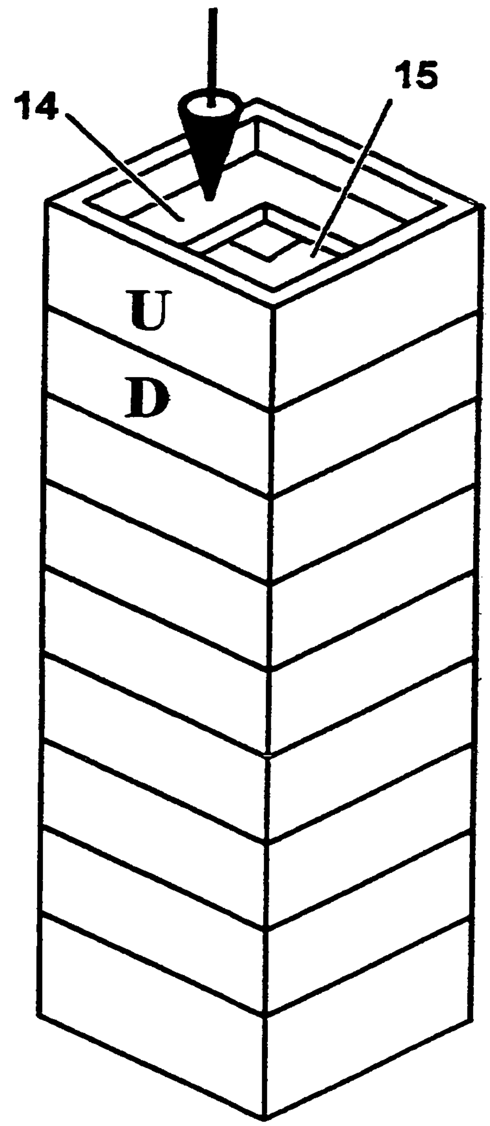


Fig. 10

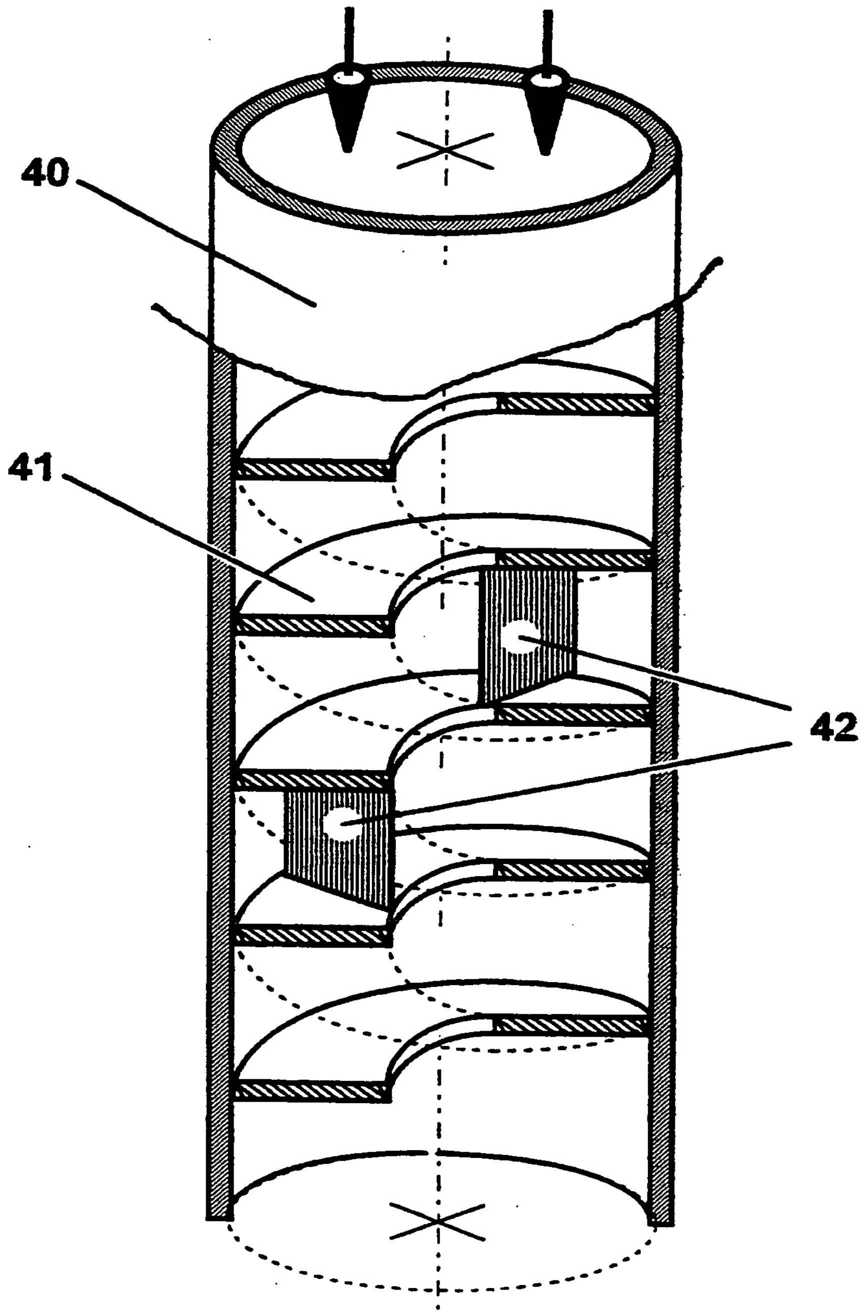


Fig. 11a

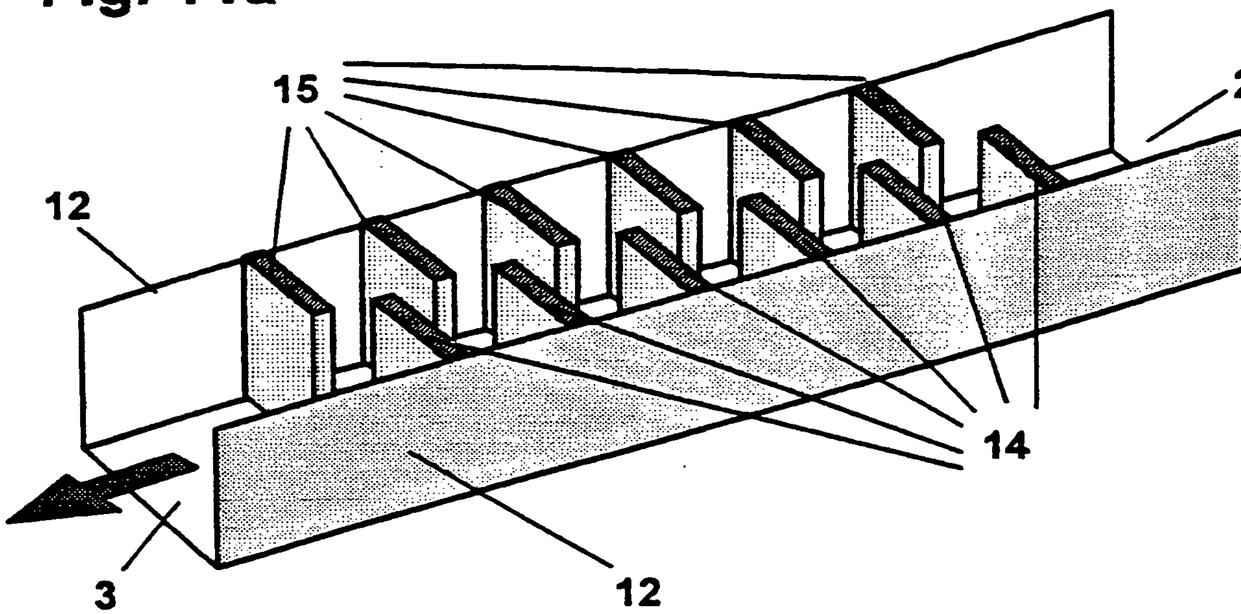


Fig. 11b

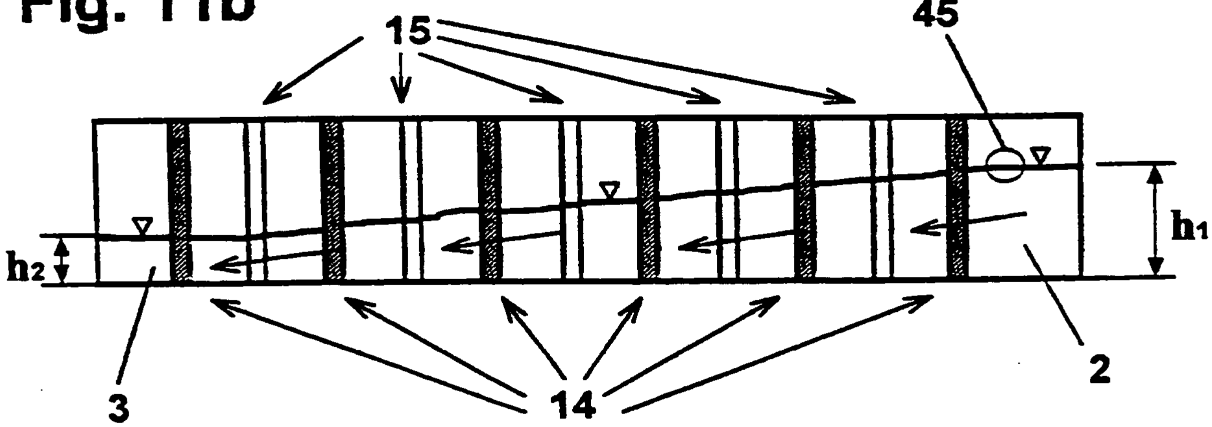


Fig. 11c

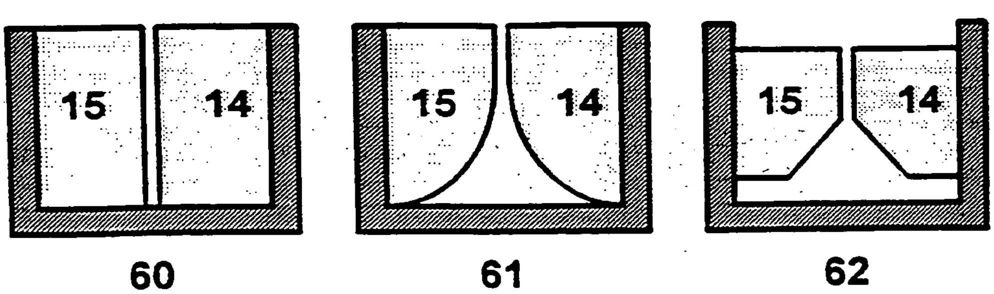
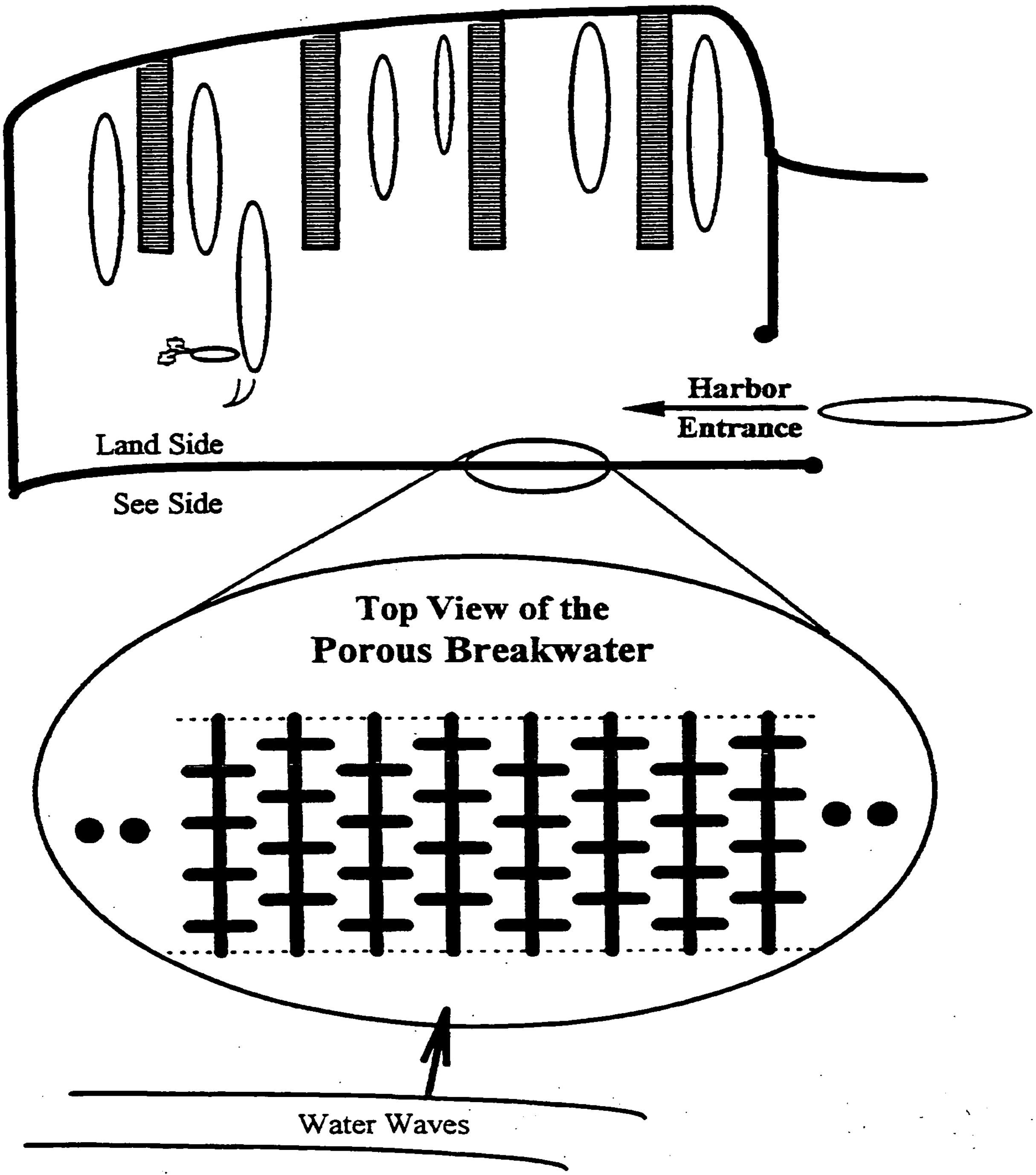


Fig. 12


Harbor
Entrance
Land Side
See Side
Top View of the
Porous Breakwater
Water Waves

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL00/00499

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :F16L 55/00
US CL :138/42
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 138/37-39, 42; 366/336-341

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 1,877,567 A (ERBES) 13 September 1932, entire document	1-94
A	US 3,785,405 A (QUINN) 15 January 1974, entire document.	1-94
A	US 4,655,397 A (GORNEY) 07 April 1987, entire document.	1-94
A	US 5,830,515 A (PLEASANT et al) 03 November 1998, entire document.	1-94

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
05 NOVEMBER 2000	28 NOV 2000

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Y. Hurley for PATRICK F. BRINSON
Facsimile No. (703) 305-3230	Telephone No. (703) 308-0111